J. People Plants Environ. Vol. 25 No. 4: 337-348, August 2022
https://doi.org/10.11628/ksppe.2022.25.4.337

JPPE

Check for updates

Selection of Companion Plants for Pest Control of Cruciferous Crops

In-Kyoung Hong[1], Hyung-Kwon Yun[2*], Young-Bin Jung[3], Sang-Mi Lee[3], and Sang-Deok Lee[3]

[1]Postdoctoral researcher, Urban Agricultural Research Division, National Institute of Horticultural and Herbal Science, Rural Development Administration, Wanju-gun, Jeolabuk-do 55365, Republic of Korea

[2]Senior researcher, Urban Agricultural Research Division, National Institute of Horticultural and Herbal Science, Rural Development Administration, Wanju-gun, Jeolabuk-do 55365, Republic of Korea

[3]Researcher, Urban Agricultural Research Division, National Institute of Horticultural and Herbal Science, Rural Development Administration, Wanju-gun, Jeolabuk-do 55365, Republic of Korea

ABSTRACT

Background and objective: This study was conducted to determine the types of pests that occur in spring and autumn on three types of cruciferous vegetables, which are host plants, and investigate the actual effect by selecting companion plants with pest control effects.

Methods: This study selected 3 types of cruciferous crops and 17 types of companion plants through literature review to investigate the types of pests and damage index occurring in spring and autumn. After examining the number of pests that occur per 10 plants on a weekly basis, the mean and standard deviation were calculated using the IBM SPSS statistics Ver. 25 program.

Results: There was little damage to pests in 17 types of herbs, flowers, and vegetables. When grown together with cruciferous vegetables, 8 types of herbs, 5 types of vegetables, and 4 types of flowers showed little pest damage. In particular, companion plants that suffered less pest damage were catnip, chamomile, thyme, and nasturtium in spring cultivation and thyme, basil, catnip, chamomile, rosemary, and marigold in autumn cultivation. Shoot growth of Kimchi cabbage and white radish in the experimental group planted with vegetables was 148–181% of the control group using conventional cultivation but companion planting with rosemary, nasturtium, and marigold showed less growth than the control group, especially the experimental group planted with rosemary, which showed 45–53% of growth compared to the control group. The companion plants with good growth in the root of white radish were celery, beet, basil, and marigold. There was little difference in the degree of pest damage to crops between the central planting with a few companion crops and the parallel, alternate, and perimeter planting with many companion crops.

Conclusion: Pests can be managed effectively with a pest management technique that utilizes the pull effect based on the interaction between frequently occurring pest types and companion plants.

Keywords: companion planting, environmentally friendly, insect pest, organic, urban agriculture

Introduction

The demand for organic farming is rapidly increasing worldwide due to changes in consumer patterns that value safety and health of agricultural products and the growing need for sustainable agriculture (FiBL and IFOAM, 2014). According to the 5th Five-year Promotion Plan for Environmentally Friendly Agriculture (2021-2025), the number of certified farms for environmentally friendly agricultural products increased by 3.5% in 2020 compared to 2018, and the certified acreage also increased by 5.2% compared to the total cultivated acreage; and the market size has been annually growing by 5.8% since 2006. As consumers recently have more and more interest in health and environment along

This paper is funded by a Rural Development Administration project (PJ01507602).
Received: March 3, 2022, **Revised:** March 23, 2022, **Accepted:** July 10, 2022
First author: In-Kyoung Hong, inkyoung63@korea.kr, https://orcid.org/0000-0002-7050-5413
***Corresponding author:** Hyung-Kwon Yun, yun0309@korea.kr, https://orcid.org/0000-0001-9973-4706

with this trend, there has been an increasing demand for environmentally friendly crop cultivation technology to stably produce agricultural products (Kim et al., 2012). Plant extracts such as sophora roots, pyrethrums, and chinaberries have been reported to have high insecticidal properties in *Myzus persicae* 'Sulzer', moths, and whiteflies (Kim et al., 2009; Hwang et al., 2009), and egg yolk oil using cooking oil and egg yolk has been developed and used for microbial pest control (Park et al., 2008). There are about 100 kinds of natural plant extracts registered as materials for organic pest management in Korea, such as neem, matrine, pyrethrum, and pepper seed (Runal Development Administration, 2011). Currently, there are 14 orders, 86 families, and 318 species of pests that occur in vegetables reported in Korea. Among them, diamondback moths, *Myzus persicae* 'Sulzer', mites, thrips, and greenhouse whiteflies have a short growing period, strong reproductivity, and many suffering households a year, thereby causing a great damage (Lee et al., 2000; Pail et al., 2009).

Some herbs and flowers produce organic compounds of terpenes and release fragrance into the air to repel pests from approaching plants and plant bodies. Companion plants are used for the purpose of blocking the inflow of pests or avoiding damage to establish an ecological pest control system for pests. As part of the push-pull farming method, the term is still unfamiliar in Korea (Cook et al., 2007; Finch and Collier, 2011; Parker et al., 2013), but the diverse terms used before such as companion plants, companion crops, and mixed food were unified and established as 'companion plants' in a relationship that helps one another or the other in the report by Hong et al. (2020), after which the term has been more widely understood (Hong et al., 2021). Chrysanthemum farms effectively attracted thrips using eggplants as a trap plant (Kang et al., 2011). In pesticide-free aquaculture of leafy vegetables, it was found that pests avoided basil, coriander, Houttuynia cordata, pyrethrum, and peppermint (Seo et al., 2009). As a result of reviewing the pull effect of Kimchi cabbage *Phyllotreta striolata* in 7 types of cruciferous crops such as gyeoja chae and leaf mustard, it was found that gyeoja chae was most effective (Ryu et al., 2012). However, vegetables have a great impact on commercialization due to quality deterioration as well as quantity reduction due to pests, and there is an urgent need for environmentally friendly pest control techniques since they are mostly eaten raw (Cook et al., 2007; Ryu et al., 2012). But since pests occur constantly, it is difficult to control them altogether, and despite the constant development and use of pest control techniques such as pheromone traps or light traps, the pest control effect is not consistent depending on the pest type or occurrence period (Kim et al., 2002; Seo et al., 2009).

Therefore, to investigate the pest control effect of companion plants that are still at an early stage of environmentally friendly agriculture in Korea, this study was conducted to select effective companion plants by validating the push-pull effect of cruciferous crops (Kimchi cabbage, white radish, kale) in companion planting against major pests.

Research Methods

Materials for the experiment

This study was conducted to select companion plants useful for environmentally friendly pest management by selecting Kimchi cabbage, white radish, and kale, which are produced the most in Korea among cruciferous crops.

Spring planting

For spring planting, to conduct both monoculture farming (1th experiment) and companion planting (2and experiment) at the same time, we selected 3 types of cruciferous crops and 5 types of aromatic vegetables (carrot '5th cousin of Shin Heukjeon', chives 'Chinabelt', beet 'Detroit Dark Red', lettuce 'Hacheong', celery 'Judas'), 8 types of herbs (catnip 'Nepeta', dill, rosemary, sweet basil, peppermint, cherry sage, common chamomile, thyme 'lemon'), and 4 types of flowers (pot marigold 'Orange Pride', French marigold, salvia 'Sprendez', nasturtium 'Holybird Mixer') among plants with the push or pull effect against insect damage according to previous studies (Hooks et al., 2013; Hong et al., 2020; Tringovska et al., 2015; Parker et al., 2013; B.I. Refka et al., 2017; Finch et al., 2003) (Table 1). Plants used in companion planting reduce pest damage on other plants around them since they are avoided or preferred by pests, and herbs such as rosemary and thyme release many com-

Table 1. Classification of crop types by cultivation period

Division		Spring cultivation	Autumn cultivation
Main crop	Cruciferae	*Brassica campestris* var. *pekinensis* 'Bulam No. 3' (Kimchi cabbage), *Brassica oleracea* 'Masjjang'(kale), *Raphanus sativus* 'Cheong-un'(white radish)	
Companion Plants	Herbs	*Ocimum basilicum* (sweet basil), *Nepeta cataria* 'Nepeta' (catnip), *Chamaemelum nobile* (common chamomile), *Anethum graveolens* (dill), *Salvia microphylla* 'Hot Lips' (sage), *Mentha piperascens* (pepper mint), *Rosmarinus officinalis* (rosemary), *Thymus vulgaris* 'Lemon' (thyme)	*O. basilicum* (sweet basil), *N. cataria* 'Nepeta' (catnip), *C. nobile* (common chamomile), *R. officinalis* (rosemary), *T. vulgaris* 'Lemon' (thyme)
	Vegetables	*Beta vulgaris* 'Detroit Dark Red' (beet), *Daucus carota* '5th cousin of Shin Heukjeon (carrot), *Apium graveolens* 'Judas' (celery), *Allium schoenoprasum* 'Chinabelt' (chives), *Lactuca sativa* 'Hacheong' (lettuce)	*B. vulgaris* 'Detroit Dark Red' (beet), *A. graveolens* 'Judas' (celery)
	Flowers	*Calendula officinalis* 'Orange Pride' (pot marigold), *Tagetes erecta* (French marigold), *Tropaeolum majus* 'Holybird Mixer' (nasturtium), *Salvia splendens* 'Sprendez' (salvia)	*T. erecta* (French marigold), *T. majus* 'Holybird Mixer' (nasturtium)

ponents avoided by insects, such as eucalypton, lemonol, linalool, limonene, and pinenes.

Autumn cropping

For autumn cropping (3rd experiment), the occurrence of insect damage by planting type was investigated with 5 types of herbs (catnip 'Nepeta', thyme 'lemon', rosemary, sweet basil, common chamomile), 2 types of aromatic vegetables (celery 'Judas', beet 'Detroit Dark Red'), and 2 types of flowers (French marigold, nasturtium 'Holybird Mixer') that showed a pest control effect in spring planting.

Experimental method

To investigate the pest control effect of companion plants, this study was conducted in total area of 332.5 ㎡ by the Urban Agricultural Research Division of the National Institute of Horticultural and Herbal Science located in Iseo-myeon, Wanju-gun, Jeollabuk-do.

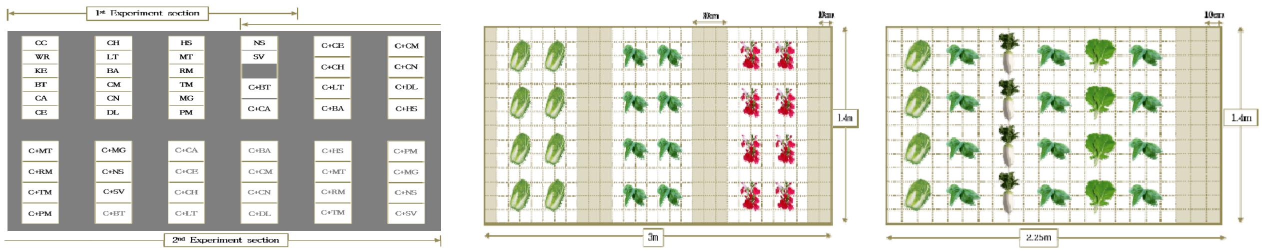
Spring planting

As the 1st experiment of spring planting, we made 12 900 x 140 cm fields to identity insect damage on plants and planted total 20 types of plants, such as 3 types of cruciferous crops (Kimchi cabbage, white radish, kale) and 17 types of companion plants, in 4 fields, 8 plants in each, keeping a 30 cm distance to prevent interference among plants and covering them with felt for distinction. In the 2and experiment, we planted companion plants in between 3 types of cruciferous crops (plant spacing 30-40 cm) (Kimchi cabbage, white radish, kale) in parallel type, 4 plants in each repeated twice, in the 8 fields of the 2and experiment and the last field of the 1st experiment to investigate pest occurrence. Here, plant spacing was adjusted on site by 30 cm according to plant length and characteristics, and we covered them with felt at 30 cm distance to minimize interference among companion plants and separately set up the edges (Fig. 1).

For spring planting of cruciferous crops such as Kimchi cabbage 'Bulam No. 3', white radish 'Cheong-un', and kale 'Masjjang', we sowed seeds on March 21 in 72-cell nursery pots using a horticultural substrate (Substrate No. 2 Baroker, Seoul Bio, Eumseong, Chungbuk, Korea). We raised the seedlings in a greenhouse maintaining the daytime and nighttime temperatures at 15-20 ℃ to prevent freezing damage and overgrowth, after which we planted them in the main fields on May 28.

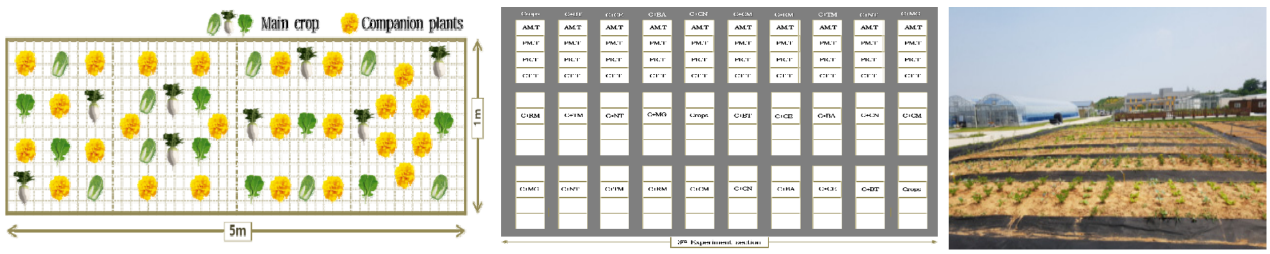
Autumn cropping

For autumn cropping (3rd experiment), we created 30 500 × 100 cm fields in 4 planting types that include not only the parallel type but also alternate type, central type, and perimeter type according to previous studies, under the hypothesis that there would be a difference in the pest control effect depending on the plantation layout. We sowed



<Layout for spring cultivation> <Single cultivation for 1st experiment> <Co-cultivation for 2nd experiment>

Fig. 1. Companion planting site of cruciferous crops for spring cultivation.



<Planting type from the left Alternate type, Perimeter type, Parallel type, Central type> <Layout for 3rd experiment> <Construction site>

Fig. 2. Cultivation method by planting type.

seeds of cruciferous crops such as Kimchi cabbage 'Bulam No. 3', white radish 'Cheong-un', and kale 'Masjjang' on July 23 in 72-cell nursery pots using a horticultural substrate (Substrate No. 2 Baroker, Seoul Bio, Eumseong, Chungbuk, Korea), which we raised in a greenhouse and then planted in the main fields on August 30. Plant spacing was retained at 30cm as did in companion planting of the 2nd experiment to avoid overlapping of cruciferous crops (2 plants per type) such as Kimchi cabbage, white radish, and kale. We planted companion plants (6 plants per type) with certain distance by planting type and repeated each treatment 3 times (Fig. 2). We examined the number of pests that occur in each crop ever week from 20 days after planting, as well as the fresh weight of crops after harvest. Pest damage on companion plants and crops due to mixed cropping was investigated based on holes on leaves or traces of feeding, as well as occurrence density.

Statistical analysis

Insect damage caused by the push and pull of companion plants was determined by calculating the mean and standard deviation using IBM SPSS statistics Ver. 25 program (IBM, NY, USA). The damage index, which is a measure for insect damage on crops, was rated on a scale of 1 'almost none (0-10%)', 2 'mild (10-30%)', 3 'moderate (30-50%)', 4 'severe (50-70%)', and 5 'very severe (70% or more)'. To test the relationship between major crops and companion plants, we conducted an analysis of variance (ANOVA) that is a statistical method to test the difference by the mean value of samples, after which we tested the significance at a 95% confidence level ($p < .05$) through Duncan's multiple range test. For autumn cropping, we tested the significance of crops with a multiple range test by examining the shoot fresh weight of Kimchi cabbage and root fresh weight of white radish harvested.

Results and Discussion

Types of pests that occur by crop in spring planting

This study planted 3 types of cruciferous vegetables (Kimchi cabbage, white radish, kale) that are major crops and 17 types of plants known as repellent plants within the experimental groups and investigated the type of pests that occur by crop in June and July. The results showed that there was high density and great damage in aromatic vegetables compared to herbs or flowers. During this period, there were damages mostly by *Phyllotreta striolata*, *Phaedon brassicae*, *Pieris rapae*, *Mamestra brassicae*, and *Eurydema dominulus*. This showed similar results as the study by Pivnick et al. (1992) stating that *Phyllotreta striolata* is attracted by the substance decomposing glucosinolate as a secondary metabolite generated in plants and Kimchi cabbage. *Thrips palmi* and *Frankliniella occidentalis* were found in carrots, and *Myzus persicae* 'Sulzer' in marigold and thyme (Table 2).

Growth and pest damage index according to companion plants for pest control of cruciferous crops in spring planting

For spring planting, pesticides were not used for pest investigation before planting and during cultivation. On June 20, about a month after planting, there was almost no pest damage in the experimental groups with companion planting, but pest damage increased from the first part of July and became severe in the middle part. There was a severe pest damage in cruciferous crops in the investigation on July 20, but there was low pest occurrence in herbs, flow-

Table 2. Types of pests that occurred in spring cultivation

Div.[z]	Crop[y]	Occurrence of pest[x]																	Total
		PS	PB	PR	PX	MB	DB	ED	TM	AD	MQ	TP	FO	CP	HE	MP	HU	PS	
C	KC	o	o	o		o		o						o					6
	KE	o	o	o		o		o						o					6
	WR	o	o	o		o		o						o					6
V	BT	o	o	o		o		o											5
	CA	o	o	o		o		o		o		o	o						8
	CE	o	o	o	o	o	o	o											7
	CH	o	o	o		o				o	o								6
	LT	o	o	o	o	o	o	o	o										8
H	BA	o	o	o		o			o										5
	CN	o	o	o		o			o						o				6
	CM	o	o	o		o	o		o					o					7
	DL	o	o	o		o		o						o	o				7
	HS	o	o	o		o		o									o		6
	MT	o	o	o		o												o	5
	RM	o	o	o		o													4
	TM	o	o	o		o										o			5
F	MG	o	o	o	o	o	o	o										o	8
	PM	o	o	o	o	o								o		o			7
	NS	o	o	o		o						o			o				6
	SV	o	o	o		o									o				5
Total		20	20	20	4	20	4	10	4	2	1	2	1	6	4	2	1	2	126

[z]C = cruciferous plants; V = vegetables; H = herbs; F = flowers.

[y]KC = Kimchi cabbage; KE = kale; WR=white radish; BT = beet; CA = carrot; CE = celery; CH = chives; LT = lettuce; BA = basil; CN = catnip; CM = chamomile; DL = dill; HS = hotlip sage; MT = mint; RM = rosemary; TM = thyme; MG = marigold; PM = pot marigold; NS = nasturtium; SV = salvia.

[x]PS = *Phyllotreta striolata*; PB = *Phaedon brassicae*; PR = *Pieris rapae*; PX = *Plutella xylostella*; MB = *Mamestra brassicae*; DB = *Dolycoris baccarum*; ED = *Eurydema dominulus*; TM = *Tenthredo mesomelus*; AD = *Acusta despecta sieboldiana*; MQ = *Monolepta quodriguttata*; TP = *Thrips palmi*; FO = *Frankliniella occidentalis*; CP = *Capsus pilifer*; HE = *Hemiptera*; MP = *Myzus persicae*; HU = *Hellula undalis*; PS =*Plautia stali*

ers, and aromatic vegetables except beet (Fig. 3).

Kimchi cabbage in the experimental group showed more than a 'moderate' level of pests in beet and lettuce (vegetable), dill and sage (herb), and salvia (flower), while the rest of the plants suffered little damage (Table 3). For kale, there was more than a 'moderate' level of pests in lettuce (vegetable), basil and sage (herb), and salvia (flower). For white radish, there was more than a 'moderate' level of pests in chives (vegetable), pot marigold and marigold (flower). In the experimental groups, companion plants that showed particularly little pest damage were catnip, chamomile, thyme (herb), and nasturtium (flower). They had good land cover

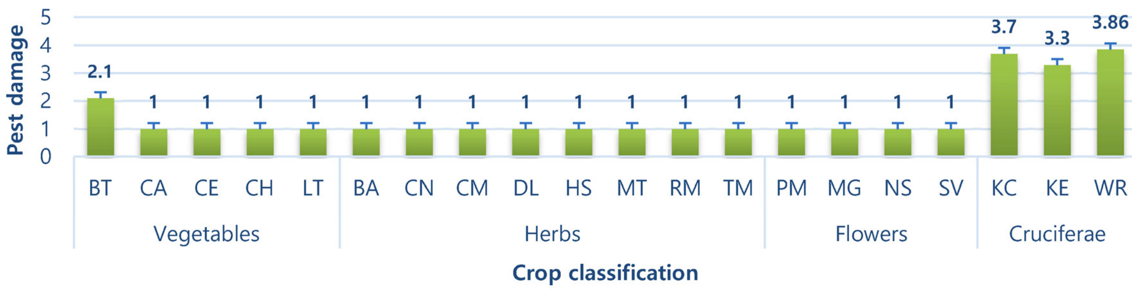


Fig. 3. Pest damage index by each crops and plants. Abbreviations of companion plants' names are derived from Table 2. Damage index; 1 (almost none) – 5 (very severe).

Table 3. Pest damage index due to companion planting of spring-grown cruciferous crops

Division	Companion crop[z]	Pest damage index[y]			
		Kimchi cabbage	White radish	Kale	Mean ± SD
Control	-	3.71 ± 1.08 ab[x]	3.92 ± 0.78 b	3.33 ± 0.96 a	3.65 ± 0.94
Vegetable	BT	3.50 ± 0.97 a	2.69 ± 1.20 a	2.75 ± 1.00 a	2.98 ± 1.10
	CA	2.50 ± 0.82 abc	2.87 ±1 .03 abc	2.50 ± 0.89 a	2.63 ± 0.91
	CE	2.56 ± 0.81 a	3.00 ± 1.10 a	2.45 ± 0.73 a	2.67 ± 0.91
	CH	2.44 ± 0.51 b	3.50 ± 1.41 b	2.75 ± 0.58 b	2.90 ± 1.02
	LT	3.38 ± 0.62 a	2.74 ± 0.45 a	3.00 ± 1.46 a	3.04 ± 0.97
Herb	BA	2.38 ± 0.50 bc	2.75 ± 0.78 bc	3.37 ± 1.20 ab	2.9 ± 0.33
	CN	2.29 ± 0.40 abc	2.00 ± 0.20 abc	2.10 ± 0.52 a	2.06 ± 0.38
	CM	2.38 ± 0.72 bc	2.50 ± 0.89 bc	2.55 ± 0.73 ab	2.46 ± 0.77
	DL	2.95 ± 1.12 abc	2.34 ± 0.62 abc	2.13 ± 0.62 a	2.48 ± 0.88
	HS	3.63 ± 0.89 abc	2.63 ± 0.72 abc	3.31 ± 1.08 a	3.19 ± 0.98
	MT	2.45 ± 0.63 abc	2.00 ± 0.16 abc	2.63 ± 0.70 a	2.37 ± 0.61
	RM	2.94 ± 1.00 a	2.31 ± 0.48 a	2.56 ± 0.73 a	2.60 ± 0.79
	TM	2.00 ± 0.15 b	2.37 ± 0.50 b	2.31 ± 0.60 b	2.23 ± 0.47
Flower	MG	2.53 ± 0.50 a	3.45 ± 1.15 a	2.44 ± 0.51 a	2.83 ± 0.88
	PM	2.83 ± 0.96 a	3.38 ± 1.09 a	2.50 ± 0.63 a	2.92 ± 0.96
	NS	2.34 ± 0.50 bc	2.00 ± 0.24 bc	2.00 ± 0.89 ab	2.13 ± 0.61
	SV	3.50 ± 1.10 a	2.63 ± 0.72 a	3.44 ± 1.09 a	3.19 ± 1.05

[z]KC = Kimchi cabbage; KE = kale; WR = white radish; BT = beet; CA = carrot; CE = celery; CH = chives; LT = lettuce; BA = basil; CN = catnip; CM = chamomile; DL = dill; HS = hotlip sage; MT = mint; RM = rosemary; TM = thyme; MG = marigold; PM = pot marigold; NS = nasturtium; SV = salvia.

[y]Damage index :1 'almost none', 2 'slightly present', 3 'usually', 4 'severe', 5 'very severe'.

[x]Mean separation within columns by Duncan's multiple range test at $p = .05$.

at the beginning, which activated the pull effect of companion plants and reduced incurrence of disease, and the short plant length improved the light environment and helped the growth of major crops (Kim et al., 2008). As a result of Duncan's multiple range test to test the significance, it was found that Kimchi cabbage did not show a statistical difference with all companion plants having the same property as major crops, but white radish showed a significant difference from beet, celery, lettuce, rosemary, marigold, pot marigold, and salvia, and kale from chive and thyme (Table 3).

In the difference in growth of major crops according to the occurrence of insect damage, the growth of companion planting with less insect damage was somewhat better than monoculture farming that showed great insect damage, but the growth was poor in catnip, mint, and dill. This is because catnip and mint show rapid growth in underground stems and high growth rate, thereby inhibiting the growth of cruciferous crops. Accordingly, it seems necessary trim some shoots in cultivation and inhibit the growth of roots by removing some to avoid damage to other crops in the garden. Duncan's multiple range test showed that there was no statistically significant difference except leaf width of salvia, and there was no difference between groups in plant length and leaf length aside from leaf width (Table 4).

Thyme can be overwintered in an open field in the low temperature season and grows vigorously even in the high temperature season. Thus, it not only shows satisfactory growth under poor environmental conditions, but also has a short plant length and grows close to the ground surface,

Table 4. Growth result of main crop by companion plants in spring cultivation

Division	Crop[z]	Plant length (cm)	Leaf length (cm)	Leaf width (cm)
Control	KC	30.95 ± 6.98 ab[y]	28.88 ± 6.29 ab	16.27 ± 2.55 ab
	KE	32.03 ± 6.45 ab	29.40 ± 5.47 ab	15.46 ± 2.26 ab
	WR	29.55 ± 4.38 ab	27.90 ± 4.74 ab	15.11 ± 4.00 ab
Experimental	BT	31.20 ± 6.18 ab	27.78 ± 4.90 ab	14.73 ± 4.39 ab
	CA	29.36 ± 6.64 ab	25.77 ± 5.19 ab	15.44 ± 4.31 ab
	CE	35.39 ± 11.55 ab	32.85 ± 9.92 b	17.19 ± 4.10 ab
	CH	35.23 ± 9.82 ab	32.38 ± 7.45 b	19.55 ± 3.69 bc
	LT	29.73 ± 9.15 ab	27.70 ± 8.57 ab	17.45 ± 2.51 ab
	BA	37.29 ± 12.81 b	27.54 ± 10.93 ab	16.17 ± 3.65 ab
	CN	28.50 ± 4.80 ab	22.44 ± 8.08 a	13.73 ± 6.07 ab
	CM	27.27 ± 8.11 ab	25.87 ± 6.68 ab	14.13 ± 4.08 ab
	DL	25.27 ± 7.73 a	21.87 ± 5.59 a	13.07 ± 4.38 a
	HS	32.86 ± 10.16 ab	24.77 ± 10.15 ab	14.76 ± 7.00 ab
	MT	30.59 ± 11.14 ab	22.43 ± 7.80 a	12.73 ± 5.84 a
	RM	29.90 ± 6.84 ab	27.77 ± 5.52 ab	15.50 ± 4.58 ab
	TM	30.80 ± 10.03 ab	28.77 ±8.83 ab	17.02 ± 4.46 ab
	MG	29.44 ± 5.00 ab	25.63 ± 8.26 ab	16.00 ± 5.68 ab
	PM	29.11 ± 8.58 ab	24.07 ± 4.96 ab	12.73 ± 4.47 a
	NS	29.97 ± 8.70 ab	25.49 ± 7.33 ab	13.91 ± 5.62 ab
	SV(splendens)	30.06 ± 5.94 ab	27.20 ± 4.54 ab	23.59 ± 8.86 c
Significant		.599[ns]	.264[ns]	.009**

[z]KC = Kimchi cabbage; KE = kale; WR = white radish; BT = beet; CA = carrot; CE = celery; CH = chives; LT = lettuce; BA = basil; CN = catnip; CM = chamomile; DL = dill; HS = hotlip sage; MT = mint; RM = rosemary; TM = thyme; MG = marigold; PM = pot marigold; NS = nasturtium; SV = salvia.

[y]Mean separation within columns by Duncan's multiple range test at $P = 0.05$.

[NS, **] Non-significant or significant at $p < .01$ by ANOVA test.

Fig. 4. Pest damage of leaves in Kimchi cabbage, white radish, kale grown without or with companion plants (thyme, catnip chamomile, and nasturtium).

and thereby it is considered a promising crop to be used as a companion plant in the garden. Basil grows tall shoots and shows high growth rate and speed, creating a shade over plants nearby. Thus, it must be trimmed occasionally to adjust shoot height considering the height of neighboring plants. Nasturtium showed favorable growth from May to mid-July, but deteriorated from late July to late August when high temperatures continued. Therefore, to cultivate companion plants in the garden, it would be adequate to do the first planting in early spring from early April to early or mid-May and grow the plants until mid-July, and then plan the seedlings again during autumn crop planting time. Moreover, nasturtium, chamomile, and dill are crops that are easy to use as companion plants in the garden since the seeds formed from the flowers are detached after spring planting and produce many buds, which are enough to plant in autumn crop planting time (Fig. 4).

Shedding new light on pest damage and growth of cruciferous crops in autumn cropping

As a result of comparing the shoot fresh weight of Kimchi cabbage and root fresh weight of white radish between the control group growing only vegetables and the experimental groups with companion plants, it was found that basil showed the best shoot fresh weight in Kimchi cabbage with 4.03 kg, followed by 3.28 kg > celery 2.68 kg > thyme 2.10 kg > catnip 1.94 kg > chamomile 1.80 kg > marigold 1.66 kg > nasturtium 1.59 kg > rosemary 0.95 kg. The experimental groups showed good growth compared to the control group (1.81 kg) in which only Kimchi cabbage grew, except chamomile, marigold, nasturtium, and rosemary. This is similar to the result by Han et al. (2015) showing that volatile components such as eugenol and methyl eugenol, which are major components of basil, served as repelling ingredients for pests and affected growth. However, beet showed good growth unlike the pest damage index, which raises the need for additional research.

The shoot of white radish showed the poorest growth in beet (0.30 kg) and basil (0.29 kg), and the control group (0.29 kg) generally showed good results, but there was no statistically significant difference between treatments except beet and basil. The root showed the best growth in beet with 1.50 kg, followed by celery 1.46 kg > basil 1.38 kg, showing better growth than the control group. With nasturtium 1.21 kg > catnip 0.94 kg > chamomile 0.87 kg > marigold 0.85 kg > thyme 0.84 kg > rosemary 0.69 kg, the experimental groups showed better growth than the control group (0.74 kg) overall except rosemary, but there was no growth difference between the experimental groups compared to the control group (Table 5). The growth of white radish, which is a root vegetable, may have been affected by the root environment regardless of pest damage on shoots.

The shoot growth of Kimchi cabbage and white radish was active in companion planting with vegetables than herbs and flowers, showing 148-181% more growth in companion planting with vegetables than the control group, but crop growth planted with rosemary, nasturtium, and marigold showed less growth than the control group. In particular, the planting combination that grew rosemary as a companion plant showed a shoot growth rate that is about 45-53% of the control group. Moreover, in the planting combinations in which catnip, thyme, chamomile, and marigold were grown as companion plants, Kimchi cabbage and crops showed little shoot growth. The root growth rate was compared with that of white radish based on the weight of white radish harvested in the control group. The companion plants showing satisfactory growth in white radish were celery and beet in vegetables; basil, catnip, chamomile, and thyme in herbs; and nasturtium and marigold in flowers. When planting crops with white radish, the growth of white radish increased by 113-203% compared to the control group. As a result of the post hoc test, Kimchi cabbage showed a statistically significant difference with basil, white radish shoot with rosemary, and root with beet, celery and basil (Table 5).

In autumn cropping, companion plants were planted around cruciferous crops that are major crops, using the perimeter type, alternate type, central type, and parallel type. Since pest damage occurred to young plants immediately after planting, pesticide was sprayed after planting, which resulted in very little pest occurrence. This may have been a result of weaker pest activity due to the decrease in pest density by pest control at an early stage of pest occurrence as well as the cooling of the weather. In the planting combination with thyme and rosemary as companion plants that showed little pest damage in spring planting, there was less pest damage in any planting method compared to other plants in autumn cropping as well. As a result of investigating pest occurrence by using 4 planting types to find an effective companion plant layout, it was found that there was little pest damage in the parallel type for Kimchi cabbage, central type for kale, and alternate type for white radish, but there was almost no difference in the degree of pest damage among planting types (Table 6). Unlike planting type, companion plants with little pest damage on crucif-

Table 5. Comparison of growth of Kimchi cabbage and white radish in the control and experimental group for autumn cultivation

Division	Companion plants	Shoot fresh weight (kg)		Root fresh weight (kg)
		Kimchi cabbage	White radish	White radish
Control	-	1.81 ± 1.17 abc[z]	0.29 ± 0.14 b	0.74 ± 0.52 a
Vegetable	Beet	3.28 ± 1.43 cd	0.30 ± 0.11 b	1.50 ± 0.59 c
	Celery	2.68 ± 1.46 bcd	0.26 ± 0.07 ab	1.46 ± 1.19 c
Herbs	Basil	4.03 ± 1.43 d	0.29 ± 0.12 b	1.38 ± 0.42 bc
	Catnip	1.94 ± 0.58 abc	0.17 ± 0.09 ab	0.94 ± 0.35 ab
	Chamomile	1.80 ± 1.34 abc	0.19 ± 0.08 ab	0.87 ± 0.50 ab
	Rosemary	0.95 ± 0.54 a	0.13 ± 0.03 a	0.69 ± 0.39 a
	Thyme	2.10 ± 1.31 abc	0.17 ± 0.10 ab	0.84 ± 0.55 a
Flowers	Nasturtium	1.59 ± 0.95 ab	0.21 ± 0.09 ab	1.21 ± 0.58 abc
	Marigold	1.66 ± 0.87 ab	0.15 ± 0.06 ab	0.85 ± 0.41 a
Significant		.001***	.072ns	.001***

[z]Mean separation within columns by Duncan's multiple range test at $p \le .05$.

ns, *** Non-significant, or significant at $p \le .001$ by ANOVA test

Table 6. Pest damage of co-cultivated crops by planting type in autumn

Crop[z]	Kimchi cabbage				Kale				White radish			
	AN[y]	CR	PR	PM	AN	CR	PR	PM	AN	CR	PR	PM
CE	1	2.5	1	1	0.5	1	2	1.5	1	1	2	3
BT	2	1.5	1	1	1.5	1	1.5	2	1	1	1.5	2
CN	1	1	0.5	1	1	1	2.5	1.5	1	1	1	3
BA	1	1	1	1	1	1	1	1.5	0	1	0.5	3
TM	1	1	1	0.5	1	1	1	1.5	0.5	1	1	1
CM	1	1	1	1.5	1.5	1	1	0.5	1.5	1	1.5	1
RM	1	1	1	1	1.5	1	1.5	1.5	1	1	1	1
MG	1	1	1	1.5	2.5	1.5	1.5	3	1	1	2	2
NS	1	1	1	0.5	0.5	1.5	2.5	1.5	1	1	1.5	2.5
Mean±SD	1.1 ± 0.31	1.2 ± 0.48	0.9 ± 0.16	1.0 ± 0.33	1.2 ± 0.58	1.1 ± 0.21	1.6 ± 0.57	1.6 ± 0.61	0.9 ± 0.39	1.0 ± 0.00	1.3 ± 0.47	2.1 ± 0.83

[y]AN = alternate type; CR = central type; PR = parallel type; PM = perimeter type.

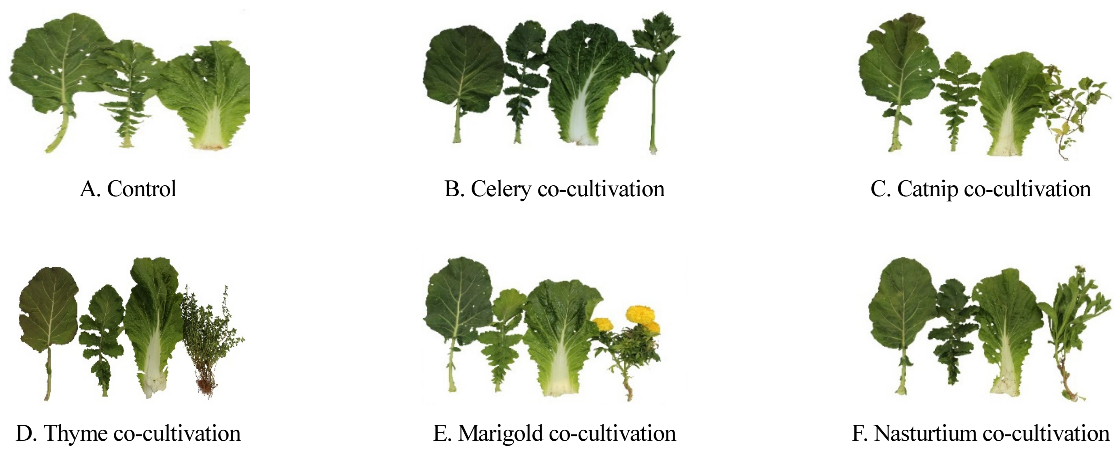


Fig. 5. Comparison of pest damage between conventional cultivation and co-cultivation with five companion crops in autumn.

erous crops in companion planting were thyme, basil, catnip, chamomile, rosemary (herb), and nasturtium (flower), which were similar to the study results by Han et al. (2015) proving that these plants can be used as repellent plants when planted with herbs in Kimchi cabbage cultivation.

For autumn cropping, pests occurred severely immediately after planting, so unlike spring planting, the registered pesticide was sprayed to Kimchi cabbage twice on September 3 and 10 according to the usage standards. There was little pest occurrence after that, and thus the plants were grown until harvest without any pest control using pesticides. As a result, as shown in Fig. 5, pest damage of the experimental group was significantly less than that of the control group.

Conclusion

This study was conducted to determine the types of pests that occur in spring and autumn, which are planting seasons, on 3 types of cruciferous vegetables and investigate the actual effect by selecting companion plants with a pest control effect. As a result of the experiment, there was almost no pest damage in 17 types of herbs, flowers and aromatic vegetables, but pest damage increased from the first part of July in spring planting for host plants that are cruciferous vegetables such as Kimchi cabbage, kale, and white radish, which became severe in mid-July. There was also severe pest damage in early September in autumn cropping, but this decreased after that. In companion planting with cruciferous vegetables, 8 types of herbs, 5 types of vegetables, and 4 types of flowers showed little pest damage, and companion plants showing little pest damage in particular were catnip, chamomile, thyme (herb), and nasturtium (flower) in spring planting, and thyme, basil, catnip, chamomile, rosemary (herb), and nasturtium (flower) in autumn cropping. Shoot growth of Kimchi cabbage and white radish in the experimental group planted with vegetables was 148-181% of the control group using conventional cultivation, but companion planting with rosemary, nasturtium, and marigold showed less growth than the control group, especially the experimental group planted with rosemary, which showed 45-53% of growth compared to the control group. The root of white radish showed 113-203% of growth compared to the control group except rosemary. The post hoc test result showed that Kimchi cabbage had a statistically significant difference with basil, white radish shoot with rosemary, and root with beet, celery, and basil. In layout by planting type of companion plants, Kimchi cabbage showed little pest damage in the parallel type, kale in the central type, and white radish in the alternate type, but there was almost no difference in pest damage to crops depending on planting type. Unlike planting type, companion plants with little pest damage to cruciferous crops in companion planting were thyme, basil, catnip, chamomile, rosemary (herb), and nasturtium (flower).

To manage pests according to the increasing diversity of plant species in gardens, it is necessary to understand the ecology of pests and analyze the interactions between various plant species and pests from multiple angles. This study validated the pest control effects of using companion plants and identified the types of pests that frequently occur as well as the accompanied effects. This will later help determine the pull effect by exploring various insect repellent substances and analyzing components for interaction with herbivores to promote use of companion plants.

References

B.I. Refka., G. Hélène, and G. Laurent. 2017. Influence of neighbouring companion plants on the performance of aphid populations on sweet pepper plants under greenhouse condition. Agricultural and Forest Entomology 19(2):181-191. https://doi.org/10.1111/afe.12199

Cook, S.M., Z.R. Khan, and J.A. Pickett. 2007. The use of push-pull strategies in integrated pest management. Annual Review of Entomology 52:375-400. https://doi.org/10.1146/annurev.ento.52.110405.091407.

FiBL and IFOAM. 2014. The world of organic agriculture: statistics and emerging trends. Yearbook. Swiss: BIOFACH Press.

Finch, S., H. Billiald, and R.H. Collier. 2003. Companion planting-do aromatic plants disrupt host-plant finding by the cabbage root fly and the onion fly more effectively than non-aromatic plants?. Entomologia Experimentalis et Applicata 109(3):183-195. https://doi.org/10.1046/j.0013-8703.2003.00102.x

Finch, S and R.H. Collier. 2011. The influence of host and non-host companion plants on the behaviour of pest insects in filed crops. Entomologia Experimentalis et Applicata. 142(2):87-96. https://doi.org/10.1111/j.1570-7458.2011.01191.x

Han, E.J., J.P. Choi, Y.K. Kim, S.J. Hong, J.H. Park, C.K. Shim, M.J. Kim, and S.C. Kim. 2015. Suppressive effect of repellent plant cultivation against striped flea beetle of Chinese cabbage. Korean Journal of Organic Agriculture 23(4):911-921. https://doi.org/10.11625/KJOA.2015.23.4.911

Hong, I.K., H.K. Yun, Y.B. Jung, S.M. Lee, and B.K. Lee. 2020. Classification of crops by type of companion plant. Journal of People, Plants, and Environment 23(Suppl. I):11.

Hong, I.K., H.K. Yun, Y.B. Jung, and S.M. Lee. 2021. A survey on the perception of companion plants for eco-friendly urban agriculture among urban residents. Journal of People, Plants, and Environment 24(1):17-27. https://doi.org/10.11628/ksppe.2021.24.1.17

Hooks, C.R., J. Hinds, E. Zobel, and T. Patton. 2013. The effects of crimson clover companion planting on eggplant crop growth, yield and insect feeding injury. International Journal of Pest Management 59(4):287-293. https://doi.org/10.1080/09670874.2013.851429

Hwang, I.C., J. Kim, H.M. Kim, D.I. Kim, S.G. Kim, S.S. Kim, and C. Jang. 2009. Evaluation of toxicity of plant extract made by neem and matrine against main pests and natural enemies. Korean Journal of Applied Entomology 48(1):87-94. https://doi.org/10.5656/KSAE.2009.48.1.087

Kang, T.J., Y.S. Choi, I.S. Hwang, H.J. Kim, and G.R. Choi. 2011. Attractant effect of trap plant and natural enemy on biological control of *Frankneiela occidentalis* in PVC chrysanthemum house. Proceedings of Symposium on Korean Society of Applied Entomologty 157. October 2011, Busan, Korea.

Kim, H.H., H.Y. Jeon, H.Y. Choo, Y.M. Choi, and M.S. Lim. 2002. Biological control of leaf beetle larva, *Phaedon brassicae* with entomopathogenic nematode. Proceedings of Symposium on Korean Society of Applied Entomology 119. May 2002, Chuncheon, Korea.

Kim, K.D., J.H. Ahn, J.T. Lee, S.C. Hong, S.W. Hwang, and C.G. Kim. 2008. Evaluation of companion crop for conservation of soil in highland cultivation of Chinese cabbage. Journal of Bio-Environment Control 17(1):1-8.

Kim, S.K., J.H. Jin, C.K. Lim, J.H. Hur, and S.Y. Cho. 2009. Evaluation of insecticidal efficacy of plant extracts against major insect pests. Korean Journal of Pesticide Science 13:165-170.

Kim, D.G., H.K. Jeong, and D.H. Moon. 2012. Production and consumption status and market prospects for environment-friendly agri-goods. KREI Report, KREI, Korea.

Lee, G.H., S.C. Lee, M.Y. Choi, and D.H. Kim. 2000. Prey consumption and suppression of vegetable aphid by *Chrysopha pallens* (Neuroptera: Chrysopidae) as a predator. Korean Journal of Applied Entomology 39(4):251-258.

Pail, C.H., G.H. Lee, D.H. Kim, M.Y. Choi, and S.S. Kim.

2009. Biological control of major pests in eggplant greenhouse. Korean Journal of Organic Agriculture 17: 227-236.

Park, J.H., K.Y. Ryu, B.M. Lee, and H.J. Jee. 2008. Effect of COY (cooking oil and yolk mixture) on control of *Tetranychus urticae*. Korean Journal of Applied Entomology 47(3):249-254. https://doi.org/10.5656/KSAE.2008.47.3.249

Parker, J.E., W.E. Snyder, G.C. Hamilton, and C. Rodriguez-Saona. 2013. Companion planting and insect pest control. In S. Soloneski and M. Larramendy (Eds.), Weed and pest control: Conventional and new challenges (pp. 1-29). IntechOpen Book 10, 55044. https://doi.org/10.5772/55044

Pivnick, K.A., R.J. Lamb, and D. Reed. 1992. Response of flea beetles, *Phyllotreta* spp., to mustard oils and nitriles in field trapping experiments. Journal of Chemical Ecology 18:863-873.

Rural Development Administration (RDA). 2011 January 11. Retrieved from http://www.rda.go.kr/matEnvofoodList.do?mode=list&prgId=mat_envofoodEntry.

Ryu, Y.H., C.S. Huh, D.G. Kim, and H.R. Park. 2012. Effect of sticky trap type and Cruciferae plant for striped flea beetle (*Phyllotreta striolata*). Proceedings of the Symposium on Korean Association of Organic Agriculture (pp. 433-434), October 2012. Suwon, Korea.

Seo, T.C., M.Y. Roh, S.C. Lee, H.C. Rhee, and G.L. Choi. 2009. Effect of interplanting leafy vegetable with insect repellent plant on the occurrence of insect pests. Korean Journal of Horticulture Science and Technology 27 (Suppl. I):92-93.

Tringovska, I., V. Yankova, D. Markova, and M. Mihov. 2015. Effect of companion plants on tomato greenhouse production. Scientia Horticulturae 186:31-37. https://doi.org/10.1016/j.scienta.2015.02.016