Available online freely at www.isisn.org

Bioscience Research

Print ISSN: 1811-9506 Online ISSN: 2218-3973

Journal by Innovative Scientific Information & Services Network

RESEARCH ARTICLE BIOSCIENCE RESEARCH, 2021 18(4): 3080-3086. **OPEN ACCESS**

Enhanced Imazethapyr Activity on Jimsonweed using natural Additives

Mani Alizadeh

Departement of Agriculture and plant breeding, Tehran, **Iran**

***Correspondence:** iauapj@gmail.com **Received 14-10-2021, Revised: 22-11-2021, Accepted: 29-11-2021 e-Published: 06-12-2021**

Identifying natural additives for agrochemicals is a primary research objective. Thus, the adjuvant activity of Fennel oil, Black seed oil, Rosewater, and Frankincense was evaluated at 0.5 and 1% (v/v) concentrations to enhance imazethapyr activity against jimsonweed (Datura stramonium L.). The dose-response curves showed that at the measured concentrations, all additives were physiologically inactive. When the additives were added to the spray solution, a substantial increase in imazethapyr activity was observed. Among the additives, only Black seed oil significantly impacted imazethapyr activity when the concentration was increased. Imazethapyr activity was increased up to 4.61-fold when fennel oil at 1% (v/v) was added. At the same time, it was increased up to 4.5 times with the addition of Frankincense at 1% (v/v) depending on the fresh weight of jimsonweed. This research established that the additives tested had a significant adjuvant effect on imazethapyr activity on jimsonweed. As a consequence, they may be ideal for development as an adjuvant based on oil.

Keywords: additive, Frankincense, Rosewater, Jimsonweed, imazethapyr activity

INTRODUCTION

An adjuvant is described as a substance that, when introduced to a spray solution enhances or alters a herbicide's activity (Cabanne 2000, Khayatnezhad and Gholamin 2020, Hou, Li et al. 2021, Ma, Ji et al. 2021). Adjuvants are classified according to their functional characteristics into five categories: extenders drift retardants, stickers, penetrants, and wetters. Chemically, the latter may be classified as mineral or vegetable (Somervaille 2011, Gholamin and Khayatnezhad 2020, Bi, Dan et al. 2021, Peng, Khayatnezhad et al. 2021, Tao, Cui et al. 2021). Even though some reports indicate that vegetable oils are less efficient than mineral oils (Huang, Wang et al. 2021, Radmanesh 2021, Rodríguez 2021), in light of environmental issues, using vegetable oils appears to be a viable alternative to mineral oils (Izadi-Darbandi, Aliverdi et al. 2013, Gholamin and Khayatnezhad 2020) due to several benefits such as biodegradability and renewable resources (Müller, Brancq et al. 2002, Hewitt 2021, Huma, Lin et al. 2021, Kabir, Arefin et al. 2021). It has been observed that extracts of medicinal plants' essential oils exhibit adjuvant action at low concentrations (Gholamin and Khayatnezhad 2020, Ren and Khayatnezhad 2021, Zhu, Saadati et al. 2021) and have herbicidal effects at higher concentrations (Cabanne 2000, Li, Mu et al. 2021).

The advantage of oil adjuvants is usually thought to be linked to their ability to (1) prolong the drying timeframe of spray droplets throughout their fly time prior to affecting the leaves, (2) avert bouncing off after affecting the leaves, (3) decrease the contact angle of the droplet with the surface of the leaf and thus enhance their spreading on the surface of the leaf, and (4) delay cryst formation (Si, Gao et al. 2020, Khayatnezhad and Gholamin 2021, Ma,

Khayatnezhad et al. 2021). A critical component of all agrochemical studies is identifying chemicals with adjuvant characteristics that increase herbicide action (Khayatnezhad and Gholamin 2020, Huang, Wang et al. 2021). As a result, we performed a series of dose-response pot trials to evaluate the effect of Fennel oil, Blackseed oil, Rosewater, and Frankincense as an oil-based adjuvant on imazethapyr activity against jimsonweed.

MATERIALS AND METHODS

In November 2019, seeds of jimsonweed were gathered from plants in the meadows of Qazvin and kept in the dark at room temperature for future usage. Bioassays were performed from June through September 2013 in a greenhouse on Mashhad's Ferdowsi University campus. Seeds were cleaned daily for seven days at a rate of one hour to eliminate seed germination inhibitors (Andersen 1968). Then, they were sterilized topically for 10 minutes with a 5 % (v/v) sodium hypochlorite solution and washed twice with distilled water. Around 25 seeds were planted in two-liter plastic pots (0.5 cm depth) with a combination of sand, clay loam soil, and peat (1:1:1 v:v:v). The pots were watered three times a week throughout cultivation. The seedlings were trimmed twice to four uniform plants per pot and treated twice with a solution of 3 g water-soluble N:P:K (20:20:20) fertilizer in 20 mL of water.

The experimental design was factorial, with imazethapyr doses (including 0, 4.69, 9.38, 18.75, 37.5, and 75 g active ingredient of imazethapyr ha^{-1}) and additives (including Black seed oil (Nigella sativa L.), Fennel Oil (Foeniculum vulgare L.), Frankincense (an aromatic gum resin obtained from Olibanum (Boswellia sacra Flueck.), The herbicide dosages used were 0%, 6%, 12%, 25%, 50%, and 100% of the indicated rate. Pursuit® (imazethapyr 10% SL, BASF, Germany) was utilized in its commercial formulation. Alkylarylpolyglycol ether (Zarnegaran Pars Company, Karaj, Iran) was used only to emulsify the components in spray solution (95% material + 5% emulsifier). An earlier investigation demonstrated that this emulsifier did not affect the action of some herbicides at the concentrations employed (Mohassel, Aliverdi et al. 2010, Gholamin and Khayatnezhad 2021, Guo, She et al. 2021). Zardband Co. in Iran provided the crude additives. The treatments were sprayed at a rate of 180 L ha^{-1} at a pressure of 200 kPa utilizing a calibrated moving boom sprayer (Matabi 121030 Super Agro 20 L; Agratech Services-Crop Spraying Equipment, Rossendale, UK) equipped with an 8002 flat-fan nozzle. The biomass of the experimental units was collected three weeks after spraying, and the weights of fresh and dried shoots were calculated. The data were transformed into individual plants and submitted to a non-linear regression analysis utilizing Ritz and Streibig's (2005) logarithmic logistic dose-response model:

$$Y = C + \{D - C / 1 + \exp[B(\log X - \log E)]\} \quad (1)$$

where Y represents the response (dry weight), C represents the lower limit, D represents the higher limit, B represents the slope of the graph, E represents the dosage needed to produce a response midway between the limits, and X is the herbicide dose. The dose-response curves were analyzed using the free and open-source statistical program R2.6.2, which included the DRC statistical addition package. The correctness of the preceding model and parameter comparisons were determined using the F-test for lack of fit at a 5% level of significance. As a result, when model 1 was evaluated, no substantial lack of fit was found; therefore, the model was satisfactory. The ED^{10}, ED^{50}, and ED^{90} values (herbicide dosage required to control jimsonweed by 10%, 50%, and 90%, respectively) were determined.

The relative potency (R), defined as the horizontal displacement between two curves (Radmanesh 2021, Rodríguez 2021), was computed as follows:

$$R = ED_{50a} / ED_{50b}; R \leq 1 \leq R \quad (2)$$

ED_{50a} is used to treat 'a' and ED_{50b} is used to treat 'b.' If R < 1, the therapy of 'a' is more effective than the treatment of 'b,' and if R > 1, the opposite is true.

RESULTS AND DISCUSSION

The dose-response graphs for imazethapyr treatment of jimsonweed in the presence of additives are presented in Figure 1. The logistic model parameters and the respective potencies of the additives evaluated on imazethapyr effectiveness in jimsonweed are listed in Table 1. Jimsonweed dose-response graphs to imazethapyr combined with each additive were substantially comparable, as shown by the same slope (b), and therefore may be regarded parallel. This implies that the additives were inert biologically at the concentrations tested.

Table 1 shows the results for ED_{10} (6.47 and 7.50 g a.i. imazethapyr ha^{-1}), ED_{50} (18.08 and 19.01 g a.i. imazethapyr ha^{-1}), and ED_{90} (50.48 and 43.54 g a.i. imazethapyr ha^{-1}) based on both fresh and dry weights of jimsonweed. Every one of these values dropped substantially in the inclusion of all additives. When the additives were added to the spray solution, the relative potency figures differed substantially from 1, suggesting a considerable increase in imazethapyr activity. The imazethapyr activity of jimsonweed was increased up to 4.61-fold by adding 1% (v/v) fennel oil. Nonetheless, when Frankincense was added at 1% (v/v) to the fresh weight of jimsonweed, it was increased up to 4.50-fold. According to the fresh weight of jimsonweed, the following additions may be ordered as per their effectiveness in increasing imazethapyr activity: At 0.5 % and 1% (v/v), respectively, fennel oil (R = 3.24 and 4.61) > Frankincense (R = 3.15 and 4.59) > Rosewater (R = 2.79 and 4.04) > Blackseed oil (R = 2.06 and 3.44).

As seen in Table 1, the dry weight data followed a nearly identical pattern to the fresh weight data, albeit with a small variation. We do not understand why these observed disparities exist. According to the dry weight of jimsonweed, the following additions were rated according to their ability to increase imazethapyr activity: When applied at a concentration of 0.5 % (v/v), fennel (R = 4.28) > Frankincense (R = 3.17) > Black seed (R = 2.24) > Rosewater (R = 2.16) However, they were rated as follows at 1% (v/v): Frankincense oil (R = 4.50) > Black seed oil (R = 3.58) > Rosewater (R = 2.92) > Fennel oil (R = 3.22) > There are no data on the impact of the tested additives as an adjuvant for herbicides, however Cabanne (2000) reported that introducing pine essential oil to spray solution at a concentration of 0.5 % (v/v) increased the activity of clodinafop-propargyl by up to 5- to 6-fold. Izadi-Darbandi, Aliverdi et al. (2013) have described the effect of some vegetable oils on the action of certain gramaticides against wild oat. They discovered a negative connection between the effectiveness of vegetable oils and their unsaturated/saturated fatty acid ratio. Additionally, vegetable oils are efficient adjuvants for various post-emergence herbicides (Nalewaja, Praczyk et al. 1995, Karasakal, Khayatnezhad et al. 2020, Khayatnezhad and Nasehi 2021).

The causes for the increase in imazethapyr activity may be attributed to many variables previously stated. Although raising the concentration of the tested additives improved the effectiveness of imazethapyr quantitatively (Table 1), the results collected showed that increasing the concentration of Blackseed oil had a substantial impact on imazethapyr activity when compared to other additives. Previously, researchers found a significant concentration impact for rapeseed oil, as their effects on phenmedipham (Muller et al., 2002(Cheng, Hong et al. 2021, Wang, Shang et al. 2021, Zheng, Zhao et al. 2021, Zhu, Liu et al. 2021) and glyphosate (Gauvrit et al., 2007) absorption and activity was lower at 0.1 % (v/v) than at 1% (v/v).

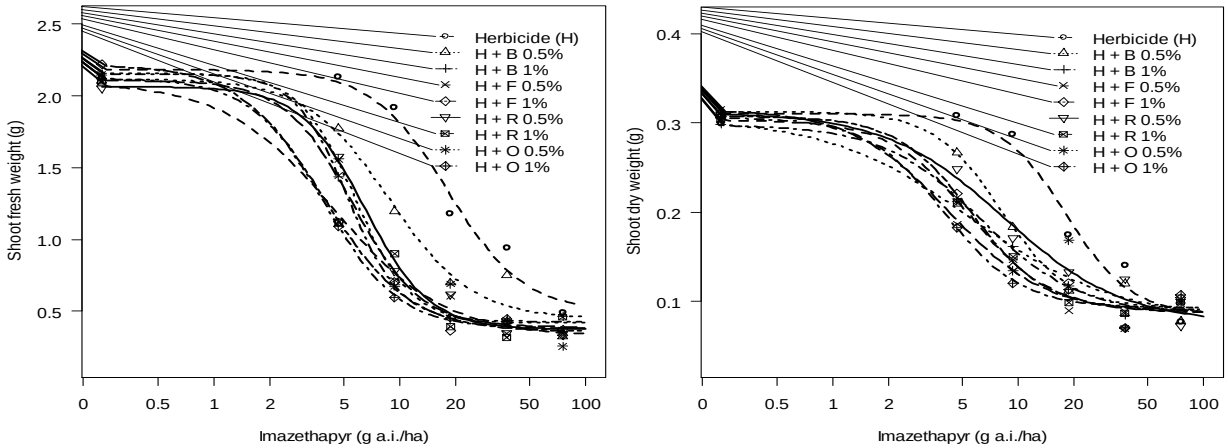

Figure 1: Dose-response curves of the shoot fresh weight (left) and shoot dry weight (right) of jimsonweed treated with imazethapyr in the presence of the additives at two concentrations of 0.5% and 1% (*v/v*). Black seed oil, Fennel oil, Rosewater (the essential oil of rose impregnated with water), and Olibanum gum resin (called Frankincense) are shortened to B, F, R, and O, respectively. The data points of each treatment were averaged over four plants per pot.

Table 1: Estimated parameters for the response curves of jimsonweed treated with imazethapyr in the presence of two concentrations of the additive

Treatments		Shoot fresh weight								
Additive	Concentration (% *v/v*)	Slope	ED_{10} (g a.i. ha^{-1})	ED_{50} (g a.i. ha^{-1})	ED_{90} (g a.i. ha^{-1})	R				
None	-	2.14 (0.66)	6.47 (1.57)	18.08 (3.37)	50.48 (3.21)	1.00				
Blackseed oil	0.5	1.94 (1.12)	2.82 (0.90)	8.75 (1.32)	27.10 (1.71)	2.06 (0.49) *	1.00			
	1	3.07 (0.83)	2.56 (0.54)	5.25 (0.46)	10.73 (2.31)	3.44 (0.71) ***	1.66 (0.29) **			
Fennel oil	0.5	2.38 (0.75)	2.22 (0.67)	5.58 (0.60)	14.02 (4.44)	3.24 (0.69) **		1.00		
	1	1.88 (1.22)	1.23 (0.61)	3.92 (0.61)	12.56 (4.45)	4.61 (1.12) **		1.42 (0.27) ns		
Rosewater	0.5	2.51 (0.72)	2.70 (0.69)	6.47 (0.70)	15.49 (4.52)	2.79 (0.60) **			1.00	
	1	2.47 (0.44)	1.00 (0.52)	4.43 (0.80)	19.56 (8.53)	4.08 (4.08) **			1.46 (0.30) ns	
Frankincense	0.5	2.87 (1.05)	2.67 (0.73)	5.74 (0.54)	12.33 (3.90)	3.15 (0.65) **				1.00
	1	2.18 (0.99)	1.44 (0.81)	3.93 (0.61)	10.75 (4.16)	4.59 (1.11) **				1.45 (0.26) ns
		Shoot dry weight								
None	-	2.50 (1.12)	7.50 (2.19)	19.01 (3.97)	43.54 (4.83)	1.00				
Blackseed oil	0.5	2.41 (0.87)	3.23 (1.13)	8.06 (1.26)	20.07 (7.59)	2.24 (0.60) *	1.00			
	1	1.63 (0.62)	1.64 (0.90)	5.30 (1.43)	24.26 (4.21)	3.58 (0.91) *	1.52 (0.35) *			
Fennel oil	0.5	1.65 (0.72)	1.12 (0.77)	5.60 (0.98)	15.88 (8.56)	4.28 (1.37) *		1.00		
	1	2.16 (0.86)	2.03 (0.87)	4.22 (0.94)	15.44 (6.80)	3.22 (0.89) *		1.32 (0.21) ns		
Rosewater	0.5	1.37 (0.67)	1.69 (0.04)	8.33 (2.81)	41.40 (3.37)	2.16 (0.87) *			1.00	
	1	2.01 (0.73)	1.84 (0.83)	6.51 (1.01)	16.43 (6.98)	2.92 (0.94) *			1.27 (0.58) ns	
Frankincense	0.5	1.20 (0.60)	0.77 (0.06)	5.68 (2.11)	41.63 (4.06)	3.17 (1.37) *				1.00
	1	2.09 (1.21)	1.40 (0.04)	4.01 (0.87)	11.46 (6.08)	4.50 (1.39) *				1.41 (0.61) ns

R is the relative potency, R = ED_{50} / ED_{50}, showing horizontal displacement between curves. Standard errors are in parentheses.
* - Statistical significance ($P \leq 0.05$); ** - Highly statistical significant ($P \leq 0.01$); *** - Very highly statistical significant ($P \leq 0.001$); ns - No statistical significant.

CONCLUSION

Since the primary obstacle to diffusing a hydrophilic herbicide such as imazethapyr into leaf tissue is the hydrophobic cuticle, oil-based adjuvants are most effective with them (Gholamin and Khayatnezhad 2020, Sun, Lin et al. 2021, Zhang, Khayatnezhad et al. 2021). On the other side, a movement toward ecologically friendly adjuvants (specifically, away from mineral oil-based adjuvants and toward vegetable oil-based adjuvants) has emerged (Zollinger 2000, Khayatnezhad and Gholamin 2021, Ma, Khayatnezhad et al. 2021, Zheng, Zhao et al. 2021), owing to their biodegradability and renewable nature. Thus, it is important to search for novel essential oils with adjuvant characteristics to enhance the effectiveness of foliar-applied herbicides (Cheng, Hong et al. 2021, Wang, Shang et al. 2021, Zheng, Zhao et al. 2021, Zhu, Liu et al. 2021). This is a simple way to decrease the risk of herbicide-related ill effects by decreasing the herbicide dosage required to control appropriate weeds (Karasakal, Khayatnezhad et al. 2020, Xu, Ouyang et al. 2021, Yin, Khayatnezhad et al. 2021). According to the results of this research, black seed oil, fennel oil, Frankincense, and rosewater all shown significant adjuvant effects for imazethapyr against jimsonweed and therefore may be appropriate for development and testing as an oil-based adjuvant (Jia, Khayatnezhad et al. 2020, Sun and Khayatnezhad 2021). It is questioned if these chemicals may jeopardize crop selectivity. Additional fieldwork is needed to address this issue.

CONFLICT OF INTEREST

The authors declared that present study was performed in absence of any conflict of interest.

ACKNOWLEGEMENT

This paper was from 1399-524695 Project, 2020, Young researchers Club.

AUTHOR CONTRIBUTIONS

Mani Alizadeh conducted, planned, Analyzed the data, wrote manuscript and interpreted the results and involved in manuscript preparation. All authors read and approved the final version.

REFERENCES

Andersen, R. N. (1968). "Germination and establishment of weeds for experimental purposes:(A Weed Science Society of America Handbook)." Germination and establishment of weeds for experimental purposes:(A Weed Science Society of America Handbook).

Bi, D., C. Dan, M. Khayatnezhad, Z. sayyah HASHJIN, Z. Li and Y. Ma (2021). "MOLECULAR IDENTIFICATION AND GENETIC DIVERSITY IN Hypericum L.: A HIGH VALUE MEDICINAL PLANT USING RAPD MARKERS MARKERS." Genetika 53(1): 393-405.

Cabanne, F. (2000). "Increased efficacy of clodinafop-propargyl by terpineols and synergistic action with esterified fatty acids." Weed Research (Oxford) 40(2): 181-189.

Cheng, X., X. Hong, M. Khayatnezhad and F. Ullah (2021). "Genetic diversity and comparative study of genomic DNA extraction protocols in Tamarix L. species." Caryologia 74(2): 131-139.

Gholamin, R. and M. Khayatnezhad (2020). "Assessment of the Correlation between Chlorophyll Content and Drought Resistance in Corn Cultivars (Zea Mays)." Helix 10(05): 93-97.

Gholamin, R. and M. Khayatnezhad (2020). "The effect of dry season stretch on Chlorophyll Content and RWC of Wheat Genotypes (Triticum Durum L.)." Bioscience Biotechnology Research Communications 13(4): 1833-1829.

Gholamin, R. and M. Khayatnezhad (2020). "Study of Bread Wheat Genotype Physiological and Biochemical Responses to Drought Stress." Helix 10(05): 87-92.

Gholamin, R. and M. Khayatnezhad (2020). "The Study of Path Analysis for Durum Wheat (Triticum durum Desf.) Yield Components." Bioscience Biotechnology Research Communications 13(4): 2139-2144.

Gholamin, R. and M. Khayatnezhad (2021). "Impacts of PEG-6000-induced Drought Stress on Chlorophyll Content, Relative Water Content (RWC), and RNA Content of Peanut (Arachis hypogaea L.) Roots and Leaves." Bioscience Research 18(1): 393-402.

Guo, L.-N., C. She, D.-B. Kong, S.-L. Yan, Y.-P. Xu, M. Khayatnezhad and F. Gholinia (2021). "Prediction of the effects of climate change on hydroelectric generation, electricity demand, and emissions of greenhouse gases under climatic scenarios and optimized ANN model." Energy Reports 7: 5431-5445.

Hewitt, E. (2021). "Ecological Plunging and Wireless Filming for Science Education: A New Zealand Pilot Experimeent." Water and Environmental Sustainability 1(1): 24-29.

Hou, R., S. Li, M. Wu, G. Ren, W. Gao, M. Khayatnezhad and F. gholinia (2021). "Assessing of impact climate parameters on the gap between hydropower supply and electricity demand by RCPs scenarios and optimized ANN by the improved Pathfinder (IPF) algorithm." Energy 237: 121621.

Huang, D., J. Wang and M. Khayatnezhad (2021). "Estimation of Actual Evapotranspiration Using Soil Moisture Balance and Remote Sensing." Iranian Journal of Science and Technology, Transactions of Civil Engineering: 1-8.

Huma, Z., G. Lin and S. L. Hyder (2021). "Promoting Resilience and Health of Urban Citizen through Urban Green Space." Water and Environmental Sustainability 1(1): 37-43.

Izadi-Darbandi, E., A. Aliverdi and H. Hammami (2013). "Behavior of vegetable oils in relation to their influence on herbicides' effectiveness." Industrial Crops and Products 44: 712-717.

Jia, Y., M. Khayatnezhad and S. Mehri (2020). "Population differentiation and gene flow in Rrodium cicutarium: A potential medicinal plant." Genetika 52(3): 1127-1144.

Kabir, K., S. M. A. Arefin and M. T. Hosain (2021). "Analysis of Momentary Variations in the Quality of Water on Specific Criteria in Cole Mere." Water and Environmental Sustainability 1(1): 8-12.

Karasakal, A., M. Khayatnezhad and R. Gholamin (2020). "The Durum Wheat Gene Sequence Response Assessment of Triticum durum for Dehydration Situations Utilizing Different Indicators of Water Deficiency." Bioscience Biotechnology Research Communications 13(4): 2050-2057.

Karasakal, A., M. Khayatnezhad and R. Gholamin (2020). "The Effect of Saline, Drought, and Presowing Salt Stress on Nitrate Reductase Activity in Varieties of Eleusine coracana (Gaertn)." Bioscience Biotechnology Research Communications 13(4): 2087-2091.

Khayatnezhad, M. and R. Gholamin (2020). "A Modern Equation for Determining the Dry-spell Resistance of Crops to Identify Suitable Seeds for the Breeding Program Using Modified Stress Tolerance Index (MSTI)." Bioscience Biotechnology Research Communications 13(4): 2114-2117.

Khayatnezhad, M. and R. Gholamin (2020). "Study of Durum Wheat Genotypes' Response to Drought Stress Conditions." Helix 10(05): 98-103.

Khayatnezhad, M. and R. Gholamin (2021). "The Effect of Drought Stress on the Superoxide Dismutase and Chlorophyll Content in Durum Wheat Genotypes." Advancements in Life Sciences 8(2): 119-123.

Khayatnezhad, M. and R. Gholamin (2021). "Impacts of Drought Stress on Corn Cultivars (Zea mays L.) At the Germination Stage." Bioscience Research 18(1): 409-414.

Khayatnezhad, M. and F. Nasehi (2021). "Industrial Pesticides and a Methods Assessment for the Reduction of Associated Risks: A Review." Advancements in Life Sciences 8(2): 202-210.

Li, A., X. Mu, X. Zhao, J. Xu, M. Khayatnezhad and R. Lalehzari (2021). "Developing the non-dimensional framework for water distribution formulation to evaluate sprinkler irrigation." Irrigation and Drainage.

Ma, A., J. Ji and M. Khayatnezhad (2021). "Risk-constrained non-probabilistic scheduling of coordinated power-to-gas conversion facility and natural gas storage in power and gas based energy systems." Sustainable Energy, Grids and Networks: 100478.

Ma, S., M. Khayatnezhad and A. A. Minaeifar (2021). "Genetic diversity and relationships among Hypericum L. species by ISSR Markers: A high value medicinal plant from Northern of Iran." Caryologia 74(1): 97-107.

Mohassel, M. H. R., A. Aliverdi, H. Hamami and E. Zand (2010). "Optimizing the performance of diclofop-methyl, cycloxydim, and clodinafop-propargyl on littleseed canarygrass (Phalaris minor) and wild oat (Avena ludoviciana) control with adjuvants." Weed biology and management 10(1): 57-63.

Müller, T., B. Brancq, A. Milius, N. Okori, C. Vaille

and C. Gauvrit (2002). "Ethoxylated rapeseed oil derivatives as novel adjuvants for herbicides." Pest Management Science: formerly Pesticide Science 58(12): 1243-1249.

Nalewaja, J. D., T. Praczyk and R. Matysiak (1995). "Surfactants and oil adjuvants with nicosulfuron." Weed Technology 9(4): 689-695.

Peng, X., M. Khayatnezhad and L. Ghezeljehmeidan (2021). "Rapd profiling in detecting genetic variation in stellaria l. (caryophyllaceae)." Genetika-Belgrade 53(1): 349-362.

Radmanesh, M. (2021). "Evaluation of the Efficient Management of Greenhouses for Healthy Items in the Province of Alborz." Water and Environmental Sustainability 1(1): 20-23.

Ren, J. and M. Khayatnezhad (2021). "Evaluating the stormwater management model to improve urban water allocation system in drought conditions." Water Supply.

Rodríguez, R. (2021). "The study of Enzyme-Water Mutualism Theory." Water and Environmental Sustainability 1(1): 44-49.

Si, X., L. Gao, Y. Song, M. Khayatnezhad and A. A. Minaeifar (2020). "Understanding population differentiation using geographical, morphological and genetic characterization in Erodium cicunium." Indian J. Genet 80(4): 459-467.

Somervaille, A. (2011). Adjuvants: Oils, surfactants and other additives for farm chemicals, Grains Research & Development Corporation.

Sun, Q., D. Lin, M. Khayatnezhad and M. Taghavi (2021). "Investigation of phosphoric acid fuel cell, linear Fresnel solar reflector and Organic Rankine Cycle polygeneration energy system in different climatic conditions." Process Safety and Environmental Protection 147: 993-1008.

Sun, X. and M. Khayatnezhad (2021). "Fuzzy-probabilistic modeling the flood characteristics using bivariate frequency analysis and α-cut decomposition." Water Supply.

Tao, Z., Z. Cui, J. Yu and M. Khayatnezhad (2021). "Finite Difference Modelings of Groundwater Flow for Constructing Artificial Recharge Structures." Iranian Journal of Science and Technology, Transactions of Civil Engineering.

Wang, C., Y. Shang and M. Khayatnezhad (2021). "Fuzzy Stress-based Modeling for Probabilistic Irrigation Planning Using Copula-NSPSO." Water Resources Management.

Xu, Y.-P., P. Ouyang, S.-M. Xing, L.-Y. Qi, M. khayatnezhad and H. Jafari (2021). "Optimal structure design of a PV/FC HRES using amended Water Strider Algorithm." Energy Reports 7: 2057-2067.

Yin, J., M. Khayatnezhad and A. SHAKOOR (2021). "EVALUATION OF GENETIC DIVERSITY IN Geranium (Geraniaceae) USING RAPD MARKER." Genetika 53(1): 363-378.

Zhang, H., M. Khayatnezhad and A. Davarpanah (2021). "Experimental investigation on the application of carbon dioxide adsorption for a shale reservoir." Energy Science & Engineering n/a(n/a).

Zheng, R., S. Zhao, M. Khayyatnezhad and S. Afzal Shah (2021). "Comparative study and genetic diversity in Salvia (Lamiaceae) using RAPD Molecular Markers." Caryologia 74(2): 45-56.

Zhu, K., L. Liu, S. Li, B. Li, M. Khayatnezhad and A. Shakoor (2021). "Morphological method and molecular marker determine genetic diversity and population structure in Allochrusa." Caryologia 74(2): 121-130.

Zhu, P., H. Saadati and M. Khayatnezhad (2021). "Application of probability decision system and particle swarm optimization for improving soil moisture content." Water Supply.

Zollinger, R. K. (2000). "Extension perspective on grower confusion in adjuvant selection." Weed Technology 14(4): 814-818.