Imidacloprid residues in farm gate tomatoes (*Solamun lycoperscicum)* of Kimira-Oluch Smallholder Farm Improvement Project, Kenya

.

ABSTRACT

**Aims:** Imidacloprid residues in farm gate tomatoes from Kimira-Oluch Smallholder Farm Improvement Project (KOSFIP) in Homa Bay County, Kenya were determined to evaluate compliance with Codex and EU residue limits.

**Study Design:** Although there were several non-registered tomato farmers in KOSFIP, samples were obtained from 30 out of the registered 34 commercial tomatoes farmers using cross-sectional survey design and simple random sampling method.

**Methodology:**  QuEChERS method for extraction followed by LC-MS/MS was used to determine the concentrations. The levels were compared with the maximum residues limits (MRLS) of EU/Codex.

**Results:**  All samples had detectable residues levels ranging from 0.025 to 0.575 mg Box plot showed a right skewed distribution, but without outliers. Data were further subjected to standardized normal distribution statistics that revealed that 19 and 28 farms produced tomatoes that satisfied EU and Codex, respectively, MRL limits. When the general use of imidacloprid was assumed to be uniform among all KOSFIP farms including unregistered farms, 62.9% and 92.92%, were within EU and Codex MRL limits, respectively. Most farmers used GAP recommended for tomatoes production, although there were 11 and 2 farms with tomatoes whose residues exceeded the EU and Codex, respectively, MRL limits.

**Conclusion:** The currently recommended rates of application of imidacloprid and post application pre-harvest period should be upheld, while intensifying extension services, regular training and surveillance to ensure all farms adopt GAP and meet regulatory residue limits.

**Key words:** *Solamun lycoperscicum;* imidacloprid; residue levels; EU/Codex limits.

1. **INTRODUCTION**

Pesticides are used in agriculture to control pests, and insect-borne diseases (Strassemeyer et al., 2017) for increased agricultural production and profitability (Wilson, 2005). Despite toxicity, pesticides are intentionally applied impacting the environment and human health negatively by causing ailments like cancer, endocrine disruption and reproductive damage (Miah et al., 2014). The degree of pesticide toxicity depends on quantity and route of exposure (Yan et al., 2021), with consumption as the primary route compared to inhalation and contact (Fothergill & Abdelghani, 2013). There is need to regularly evaluate commonly consumed foodstuffs, like tomatoes, whose production require regular use of pesticides e.g. imidacloprid to ensure food safety, and compliance to regulatory guidelines.

Tomato is a leading Kenyan vegetable in terms of production and value after potatoes (Karuku et al., 2017). The vegetable fruit is a source of vitamin C, phosphorus and calcium and has lycopene, which is an anti-inflammatory and an antioxidant that prevents prostate cancer (Collins et al., 2022). However, tomatoes are susceptible to pests infestations (Fuentes et al., 2017), that reduce both quality, and quantity (Ochilo et al., 2019). Consequently, pesticides such as imidacloprid are applied to curb pest menace. Imidacloprid, a registered pesticide in Kenya (PCPB, 2018)) for insect pests control in tomatoes (Sigei et al., 2014). Despite being among the best-selling pesticides in 2000, European Union banned its use on open field crops in 2018 due to its potential to collapse bee population (Pang et al., 2020). Though imidacloprid has low toxicity (Keil et al., 2014), chronic exposure can lead to bioaccumulation in humans causing endocrine disruption, neurotoxicity, reproductive damage, immunologic effects (Lovaković et al., 2021).

Kimira Oluch Smallholder Farm Improvement Project, (KOSFIP) is an irrigation scheme project in Homa Bay County, Kenya, established to enable smallholder farmers to grow crops in all seasons (Odoyo, 2013). KOSFIP experiences high temperatures and humidity, which encourages insect pest infestations (Cilas et al., 2016). The tomato farmers in KOSFIP therefore apply imidacloprid to curb pest infestations (Odoyo, 2013). It is the preferred pesticide at KOSFIP since it effectively overcomes pest resistance problems (Kumar et al., 2017) and has short pre-harvest interval of only 3 days when used on tomatoes (NRA, 2011). Following good agricultural practices (GAP) ensures produce complies with food safety requirements. The EU set maximum residue limit (MRL) is 0.3mg (EFSA, 2021) while CODEX limit is 0.5mg (FAO/WHO, 2004) in tomatoes. In food crops production, farmers who apply GAP usually meet the recommended MRL limits (Akiyama et al., 2024; Khandelwal et al., 2022). Farmers using imidacloprid as recommended in tomato production and complying with GAPs should therefore have farm gate tomatoes whose MRLs are be in compliance with regulatory limits (Leong et al., 2020). The levels of imidacloprid residues in tomatoes produced at KOSFIP are not documented and it is not known if the farmers are using the GAP guidelines. This study assessed the imidacloprid residue levels in farm gate tomato fruits produced at KOSFIP and their compliance with GAP guidelines.

2. **MATERIALS AND METHODS**

This study was conducted at KOSFIP, along the shores of Lake Victoria, in Homa Bay County, Kenya. (latitudes 0o 20' S and 0o 30' S and longitudes 34o 30' E and 34o 39' E (Figure 1), altitude 1277m amsl), temperatures 18-31℃, humidity 60-75% and evapotranspiration rates 1,800-2,000 mm per annum) (Odoyo, 2013). KOSFIP is an irrigation farm project (Odoyo, 2013) where farmers cultivate vegetables, including tomatoes (Makone, 2021). The area receives unreliable biannual rainfall ranging from 740 mm to 1,200 mm, necessitating irrigation using water from Tende (Oluch) and Kibuon (Kimira) rivers. KOSFIP is located on the lowland plains, with generally fertile black cotton soils suitable for agricultural production (GOK & ADF, 2006).



*Figure 1: Map of Kimira Oluch, Homa Bay County*

This study used cross-sectional survey design to assess imidacloprid residue levels in farm gate baskets tomatoes. KOSFIP had approximately 600 registered farmers, with 167 doing horticulture, of which 34 were commercially registered tomato farmers. Several farmers are not registered to produce tomatoes, but cultivate the vegetable on small-scale for domestic use and local markets. Sample size was determined using Krejcie and Morgan (1970) table. Cross section survey procedure was used to do sampling. The tomato samples were obtained at farm gates from 30 registered commercial tomatoes producers with ready Ansal variety tomatoes using simple random sampling procedure. One kilogram of freshly harvested tomatoes fruits was collected from each farm gate basket, replicated three times in the same day. The samples were kept in pre-cleaned zip-lock bags and stored at -4 awaiting analysis.

Samples processing, preparations, extractions and partitioning for imidacloprid analysis was done using Quick Easy Cheap Effective Rugged and Safe (QuEChERS) multi-residue method (Badawy et al., 2019). Tomato samples were chopped into small pieces using stainless steel knife and homogenized with a Stephan Chopper food processor. Approximately 100 g of the homogenized samples were placed in sample containers, then stored at -18 in readiness for extraction. Ten grams of homogenous wet samples were weighed into 50 mL centrifuge tubes and 50 µL of Malathion D10 (10 ppm) was added as internal standard. One of the control samples was fortified with 10 mg imidacloprid internal standard solution to achieve the 0.01 mg for LC – MS/MS analysis. To the contents in the centrifuge tube, 10.0 mL extraction solvent acetonitrile (MeCN) HPLC grade was added, closed and shaken vigorously by Geno grinder (2010) for 1 minute at 1000 revolutions per minute (rpm). The resulting homogenous mixture in the centrifuge tube was then subjected to liquid-liquid partitioning using 6.5 g of premixed QuEChERS extraction salts (4g magnesium sulphate anhydrous, 1.0 g sodium chloride, 1.0 g tri-sodium citrate dihydrate and 0.5 g sodium hydrogen citrate sesquihydrate). Anhydrous magnesium sulphate was used to remove water and salting out acetonitrile (MeCN); sodium chloride was added to increase selectivity of analyte by reducing amount of co-extracted matrix; trisodium citrate dihydrate and sodium hydrogen citrate sesquihydrate as a citrate buffer for pH adjustment. The tube was closed and immediately shaken vigorously by hand for 1 minute to avoid caking. The mixture was again shaken by Geno grinder (2010) for 1 minute at 1000 rpm then centrifuged for 5 minutes at 3700 rpm at 250C to allow phase separation of the mixture. An aliquot of 500 µL of the mixture was transferred into a 2.0 mL vial, followed by 495 µL of HPLC grade water and 5 µL of injection internal standard dimethoate D6 (10 ppm). The mixture was vortexed to mix for LCMS/MS analysis on Agilent Technologies 1290 Infinity II coupled to a triple quadrupole mass detector (Agilent 6460) using silica- based, reversed-phased C18 column. The column temperature was set at 400C, the injection volume was 0.3 µl using of a robotic auto sampler and the binary solvent elution gradient was as in Table 1 at a flow rate 3 ml . Limit of detection (LOD) was 0.01 while limit of quantitation (LOQ) was 0.01 mg/kg. The peaks were recorded in the chromatogram and quantified.

**Table 1: Solvent composition timetable**

|  |  |  |  |
| --- | --- | --- | --- |
| **Series** | **Time** | **Elution gradient with 0.01% formic Acid** | |
| 1 | 0-3min | 95% Water | 5% Acetonitrile |
| 2 | 3-7min | 50% Water | 50% Acetonitrile |
| 3 | 7-15min | 5% Water | 95% Acetonitrile |

*Note: mobile phase = Acetonitrile and water both with 0.01% formic acid*

The results were subjected to descriptive statistics. A box plot was constructed to determine the distribution and possible outliers (Kaur et al., 2018). Since the sample size was large, the normal distribution statistics (Z-statistics) was used to determine the percent KOSFIP farmers whose farm gate tomatoes had MRLs above or below the EU limit (0.3 mg ) (EFSA, 2021) and Codex limit (0.5mg ) (FAO/WHO, 2004), respectively.

3. **RESULTS AND DISCUSSION**

The imidacloprid residue levels in farm gates tomatoes of KOSFIP ranged from 0.025 to 0.575 mg (Table 2), with mean of 0.242 mg , median of 0.188 mg , standard deviation of 0.175 mg (Table 3).

**Table 2: Imidacloprid residues levels in the farm-gate baskets of tomatoes from KOSFIP area**

|  |  |  |  |
| --- | --- | --- | --- |
| Farm | Mean concentration (mg ) | Farm | Mean concentration (mg ) |
| F1 | 0.025 | F16 | 0.275 |
| F2 | 0.025 | F17 | 0.025 |
| F3 | 0.175 | F18 | 0.175 |
| F4 | 0.450 | F19 | 0.375 |
| F5 | 0.575 | F20 | 0.175 |
| F6 | 0.325 | F21 | 0.025 |
| F7 | 0.025 | F22 | 0.450 |
| F8 | 0.175 | F23 | 0.250 |
| F9 | 0.300 | F24 | 0.250 |
| F10 | 0.225 | F25 | 0.575 |
| F11 | 0.025 | F26 | 0.325 |
| F12 | 0.175 | F27 | 0.025 |
| F13 | 0.575 | F28 | 0.175 |
| F14 | 0.200 | F29 | 0.175 |
| F15 | 0.550 | F30 | 0.150 |

*Note: F= KOSFIP farms: Limit of Detection (LOD) =0.010 mg : Replicates per farm = 3*

The statistical measures of central tendency and dispersion of imidacloprid residue levels in *Solanum lycopersicum* Ansal at farm gate baskets of KOSFIP area are outlined in Table 3.

**Table 3. Measurement of central tendency and dispersion of imidacloprid residue levels in tomato at the farm gate baskets of KOSFIP area**.

|  |  |
| --- | --- |
| **The data points** | **Value** |
| Minimum | 0.025 |
| 1st Quartile (Q1) | 0.150 |
| Median (Q2) | 0.188 |
| 3rd quartile (Q3) | 0.325 |
| Inter Quartile range | 0.175 |
| Maximum | 0.575 |
| Range | 0.550 |
| Mean | 0.242 |
| Standard deviation | 0.175 |

The data was used to generate a box plot (Figure 2), that showed a right skewed distribution. There were no outliers demonstrating the KOSFIP tomato farmers were applying almost uniform imidacloprid use practices. Since the sample size was large (30), the data was subjected to z-statistics showed 62.9% of the farms had imidacloprid levels within the EU acceptable MRL (0.03mg/kg) (EFSA, 2021), while 92.92% had acceptable Codex MRL (0.05mg/kg) (FAO/WHO, 2004). Thus 37.1% and 7.1% of the farms had tomatoes exceeding EU (EFSA, 2021) and Codex (FAO/WHO, 2004) MRL limits, respectively.

|  |  |  |  |  |  |  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- | --- |
| **0.0** | **0.05** | **0.1** | **0.15** | **0.2** | **0.25** | **0.3** | **0.35** | **0.4** | **0.45** | **0.5** | **0.55** | **0.6** |

***Figure. 2. Farm gate distribution of imidacloprid residues levels in tomatoes at KOSFIP***.

The median imidacloprid residues in the farm gate tomatoes was 0.188 mg (Table 3) demonstrating that most of the farm gate tomatoes had their residues below the EU (Abdallah et al., 2017; EFSA, 2021) and Codex (FAO/WHO, 2004) acceptable limits. These results were similar to findings at Luckdown, India (Kapoor et al., 2013), Mwea (Momanyi et al., 2022), Imenti North (Marete et al., 2020) and Nairobi (Nguetti et al., 2018), in Kenya where most of tomatoes samples had residual levels below the EU MRL (EFSA, 2021), but varied with those from Buuri farms in Kenya (Marete et al., 2020). Farmers that use GAPs produce crops with within the recommended residues levels (Akiyama et al., 2024; Khandelwal et al., 2022). Most farms at KOSFIP were producing tomatoes with imidacloprid residues levels conforming to EU-MRL (EFSA, 2021), suggesting good compliance to GAPs. Such trends had been reported in Spain (Chiron et al., 1995) and Wafra and Abdally in Kuwait (Taha, 2013). The KOSFIP farms with tomatoes whose imidacloprid residues levels were above the EU MRL limit were higher than those observed in studies in Kuwait (12.5%) (Jallow et al., 2017) and Spain (4.8%) (Fernández-Alba et al., 2000). Therefore, at KOSFIP there is need to intensify trainings and extension services to ensure all farmers comply with MRL requirements.

4. Conclusion

Most of the KOSFIP tomato farmers observed GAPs with respect to imidacloprid use. However, there is need to intensify surveillance and training to ensure all farmers implement GAPs with respect to imidacloprid use to ensure all farmers compliant and to improve consumer safety.

**COMPETING INTERESTS DISCLAIMER:**

Authors have declared that they have no known competing financial interests OR non-financial interests OR personal relationships that could have appeared to influence the work reported in this paper.

References

Abdallah, O., Abdel Ghani, S., & Hrouzková, S. (2017). Development of validated LC-MS/MS method for imidacloprid and acetamiprid in parsley and rocket and evaluation of their dissipation dynamics. *Journal of Liquid Chromatography & Related Technologies*, *40*(8), 392-399. <https://doi.org/https://doi.org/10.1080/10826076.2017.1310112>

Akiyama, H., Iwasaki, Y., & Ito, R. (2024). Basic principles for setting mrls for pesticides in food commodities in Japan. *Food Safety*, *12*(2), 34-51. <https://doi.org/https://doi.org/10.14252/foodsafetyfscj.D-23-00011>

Badawy, M. E. I., Ismail, A. M. E., & Ibrahim, A. I. H. (2019). Quantitative analysis of acetamiprid and imidacloprid residues in tomato fruits under greenhouse conditions. *Journal of Environmental Science and Health, Part B*, *54*(11), 898-905. <https://doi.org/https://doi.org/10.1080/03601234.2019.1641389>

Chiron, S., Valverde, A., Fernandez-Alba, A., & Barceló, D. (1995). Automated sample preparation for monitoring groundwater pollution by carbamate insecticides and their transformation products. *Journal of AOAC International*, *78*(6), 1346-1352. <https://doi.org/https://doi.org/10.1093/jaoac/78.6.1346>

Cilas, C., Goebel, F.-R., Babin, R., & Avelino, J. (2016). Tropical crop pests and diseases in a climate change setting—a few examples. In *Climate change and agriculture worldwide* (pp. 73-82). Springer. <https://doi.org/10.1007/978-94-017-7462-8_6>

Collins, E. J., Bowyer, C., Tsouza, A., & Chopra, M. (2022). Tomatoes: An extensive review of the associated health impacts of tomatoes and factors that can affect their cultivation. *Biology*, *11*(2), 239. <https://doi.org/https://doi.org/10.3390/biology11020239>

EFSA. (2021). The 2019 European Union report on pesticide residues in food. *EFSA Journal*, *19*(4), e06491. <https://doi.org/https://doi.org/10.2903/j.efsa.2021.6491>

FAO/WHO. (2004). Food Standards Programme. *Proceedings of Codex Alimentarius Commission, Twenty-Seventh Session, 28th June - 3rd July*, 1–103.

Fernández-Alba, A. R., Tejedor, A., Agüera, A., Contreras, M., & Garrido, J. J. J. o. A. I. (2000). Determination of imidacloprid and benzimidazole residues in fruits and vegetables by liquid chromatography–mass spectrometry after ethyl acetate multiresidue extraction. *83*(3), 748-755. <https://doi.org/https://doi.org/10.1093/jaoac/83.3.748>

Fothergill, A., & Abdelghani, A. (2013). A review of pesticide residue levels and their related health exposure risks. *WIT Transactions on Ecology the Environment*, *170*, 195-205. <https://doi.org/10.2495/FENV130181>

Fuentes, A., Yoon, S., Kim, S. C., & Park, D. S. (2017). A robust deep-learning-based detector for real-time tomato plant diseases and pests recognition. *Sensors*, *17*(9), 2022. <https://doi.org/> <https://doi.org/10.3390/s17092022>

GOK, & ADF. (2006). *Kimira-Oluch Smallholder Farm Improvement Project Appraisal Report*. A. D. Fund. African Development Fund

Jallow, M. F. A., Awadh, D. G., Albaho, M. S., Devi, V. Y., & Ahmad, N. (2017). Monitoring of pesticide residues in commonly used fruits and vegetables in Kuwait. *International Journal of Environmental Research Public health*, *14*(8), 833. <https://doi.org/https://doi.org/10.3390/ijerph14080833>

Kapoor, U., Srivastava, M. K., Srivastava, A. K., Patel, D. K., Garg, V., & Srivastava, L. P. (2013). Analysis of imidacloprid residues in fruits, vegetables, cereals, fruit juices, and baby foods, and daily intake estimation in and around Lucknow, India. *Environmental Toxicology and Chemistry*, *32*(3), 723-727. <https://doi.org/https://doi.org/10.1002/etc.2104>

Karuku, G. N., Kimenju, J. W., & Verplancke, H. (2017). Farmers’ perspectives on factors limiting tomato production and yields in Kabete, Kiambu County, Kenya. *East African Agricultural Forestry Journal*, *82*(1), 70-89. <https://doi.org/https://doi.org/10.1080/00128325.2016.1261986>

Kaur, P., Stoltzfus, J., & Yellapu, V. (2018). Descriptive statistics. *International Journal of Academic Medicine*, *4*(1), 60-63. <https://doi.org/10.4103/IJAM.IJAM_7_18>

Keil, A. P., Daniels, J. L., & Hertz-Picciotto, I. H. (2014). Autism spectrum disorder, flea and tick medication, and adjustments for exposure misclassification: the CHARGE (CHildhood Autism Risks from Genetics and Environment) case–control study. *Environmental Health*, *13*, 1-10. <https://doi.org/https://doi.org/10.1186/1476-069X-13-3>

Khandelwal, A., Joshi, R., Shrivastava, M., & Singh, R. (2022). Maximum residue limit (MRL) of pesticides and their global significance. <https://doi.org/10.30954/0974-1712.02.2022.13>

Krejcie, R. V., & Morgan, D. W. (1970). Sample size determination table. *Educational and Psychological Measurement*, *30*, 607-610.

Kumar, R., Mahla, M. K., Singh, B., Ahir, K. C., & Rathor, N. C. (2017). Relative efficacy of newer insecticides against sucking insect pests of brinjal (Solanum melongena). *Journal of Entomology Zoology Studies*, *5*(4), 914-917.

Leong, W.-H., Teh, S.-Y., Hossain, M. M., Nadarajaw, T., Zabidi-Hussin, Z., Chin, S.-Y., . . . Lim, S.-H. E. (2020). Application, monitoring and adverse effects in pesticide use: The importance of reinforcement of Good Agricultural Practices (GAPs). *Journal of Environmental Management*, *260*, 109987. <https://doi.org/https://doi.org/10.1016/j.jenvman.2019.109987>

Lovaković, B. T., Kašuba, V., Sekovanić, A., Orct, T., Jančec, A., & Pizent, A. (2021). Effects of sub-chronic exposure to imidacloprid on reproductive organs of adult male rats: antioxidant state, DNA damage, and levels of essential elements. *Antioxidants*, *10*(12), 1965. <https://doi.org/https://doi.org/10.3390/antiox10121965>

Makone, S. (2021). *Impact of irrigation technologies promoted through project extension approach on farming system and crop productivity in Oluch-Kimira, Kenya* [Doctoral Dissertation, Kisii University].

Marete, G. M., Shikuku, V. O., Lalah, J. O., Mputhia, J., & Wekesa, V. W. (2020). Occurrence of pesticides residues in French beans, tomatoes, and kale in Kenya, and their human health risk indicators. *Environmental Monitoring and Assessment*, *192*, 1-13. <https://doi.org/https://doi.org/10.1007/s10661-020-08662-y>

Miah, S. J., Hoque, A., Paul, A., & Rahman, A. (2014). Unsafe use of pesticide and its impact on health of farmers: a case study in Burichong Upazila, Bangladesh. *Cancer*, *21*(3), 22-30.

Momanyi, V. N., Keraka, M. N., Abong’o, D. A., & Warutere, P. N. (2022). Comparison of Pesticide Residue Levels in Tomatoes from Open Fields, Greenhouses, Markets and Consumers in Kirinyaga County, Kenya. *European Journal of Nutrition & Food Safety*, *14*(6), 1-10.

Nguetti, J. H., Imungi, J. K., Okoth, M. W., Wangâ, J., Mbacham, W. F., & Mitema, S. E. (2018). Assessment of the knowledge and use of pesticides by the tomato farmers in Mwea Region, Kenya. *African Journal of Agricultural Research*, *13*(8), 379-380. <https://doi.org/https://academicjournals.org/journal/AJAR/article-full-text-pdf/653EA4256107.pdf>

NRA. (2011). *Imidacloprid In The Product Confidor Insecticide* <https://www.apvma.gov.au/sites/default/files/publication/13821-prs-imidacloprid.pdf>

Ochilo, W. N., Nyamasyo, G. N., Kilalo, D., Otieno, W., Otipa, M., Chege, F., . . . Lingeera, E. K. (2019). Characteristics and production constraints of smallholder tomato production in Kenya. *Scientific African*, *2*, e00014. <https://doi.org/https://doi.org/10.1016/j.sciaf.2018.e00014>

Odoyo, C. (2013). Factors Affecting Implementation of Community Projects: Case of KimiraOluch Smallholder Farm Improvement Project in Homa Bay County, Kenya. *Universal Journal of Management*, *1*(2), 111-118. <https://doi.org/10.13189/ujm.2013.010211>

Pang, S., Lin, Z., Zhang, Y., Zhang, W., Alansary, N., Mishra, S., & Bhatt, P. (2020). Insights into the toxicity and degradation mechanisms of imidacloprid via physicochemical and microbial approaches. *Toxics*, *8*(3), 65. <https://doi.org/> <https://doi.org/10.3390/toxics8030065>

PCPB. (2018). *Pest Control Products Board. In List of Registered Products for use in Kenya*.

Sigei, G. K., Ngeno, H. K., Kibe, M. A., Mwangi, M., & Mutai, M. C. (2014). Challenges and strategies to improve tomato competitiveness along the tomato value chain in Kenya. *International Journal of Business Management*, *9*(9), 205-212. <https://doi.org/10.5539/ijbm.v9n9p205>

Strassemeyer, J., Daehmlow, D., Dominic, A. R., Lorenz, S., & Golla, B. (2017). SYNOPS-WEB, an online tool for environmental risk assessment to evaluate pesticide strategies on field level. *Crop protection*, *97*, 28-44. <https://doi.org/https://doi.org/10.1016/j.cropro.2016.11.036>

Taha, F. K. (2013). Agricultural Development in Kuwait with Special Reference to. *Irrigation Agricultural Development: Based on an International Expert Consultation, Baghdad, Iraq, 24 February-1 Marc*, 347.

Wilson, C. (2005). Exposure to pesticides, ill‐health and averting behaviour: costs and determining the relationships. *International Journal of Social Economics*, *32*(12), 1020-1034. <https://doi.org/https://doi.org/10.1108/03068290510630980>

Yan, X., Zhou, Y., Liu, X., Yang, D., & Yuan, H. (2021). Minimizing occupational exposure to pesticide and increasing control efficacy of pests by unmanned aerial vehicle application on cowpea. *Applied Sciences*, *11*(20), 9579. <https://doi.org/> <https://doi.org/10.3390/app11209579>