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CONTENTS

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Suan Sunandha Science and Technology Journal

Calcium Lactate as Renewable Filler of Polypropylene: Thermal, Morphological and Mechanical Properties

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Abstract

Polypropylene (PP) composites were prepared with calcium lactate (CL) at various loading levels (10-40 wt%) by melt mixing then injection molding. The resulting properties of composites were investigated by melt flow index, optical microscopy, differential scanning calorimetry, tensile, flexural and impact mechanical tests. The tensile/flexural moduli increased with increasing CL content, while the elongation at break decreased with increasing CL content. The highest tensile/flexural strengths and impact strength were found at 10 wt% CL content. The crystallization of PP initiated at higher temperature as a result of CL addition. The smaller spherulite size with the presence of CL provided the higher tie molecules, thus improving impact strength. The influence of the maleic anhydride grafted polypropylene (MAPP) as coupling agent on the properties of PP containing 10 wt% CL content was examined. The results revealed that the MAPP gave an insignificant improvement in the final properties of the composites.

Keywords: Biocomposite, Renewable filler, Calcium lactate, Polypropylene, Crystallization

1. Introduction

Nowadays, the growing environmental awareness and the concept of sustainability are the crucial factors to the use of eco-friendly materials. Therefore, the polymer-based bio-composites have been an increasing attraction to many industries (Oliver-Ortega et al., 2018). Hence, many research pay attention to the usage of petroleum-based thermoplastic filled with fillers extracted from natural and renewable resources. Because of its low cost, heat and thermal stability as well as easy processability, polypropylene (PP) is one of the most widely used thermoplastic among the petroleum-based polymers. It has application in numerous areas such as housewares, packaging, electric sectors and automobiles, etc. PP is currently combined with various bio-based renewable fillers in order to serve specific objectives or requirements, including coir, jute, kenaf, biochar, coffee grounds and sawdust, etc. (Bledzki, Franciszczak, Osman, & Elbadawi, 2015; Das, Bhattacharyya, Hui, & Lau, 2016; Essabir et al., 2018; Mir, Nafsin, Hasan, Hasan, & Hassan, 2013; Oliver-Ortega et al., 2018). However, due to difference in polarity, a poor interfacial adhesion between bio-based fillers and PP is a main drawback. This can be defeated by chemical treatment of filler or using coupling agents. Mir et al. revealed that the mechanical improvement of coir fiber filled PP composites was attributed to good interfacial adhesion between the coir fiber and PP matrix upon chemical treatment (Mir et al., 2013). A similar trend was published by Oliver-Ortega et al. (2018). They presented that the maleic anhydride grafted polypropylene (MAPP) as the coupling agent offered a strong interfacial adhesion between rapeseed sawdust and PP, that resulted in improved mechanical properties. The use of bio-based fillers provided not only the mechanical improvement, but also the crystallization ability enhancement. Das et al. (2016) reported that the presence of biochar initiated faster crystallization for PP. The biochar shifted the crystallization to higher temperature as compared to neat PP.

Calcium lactate (CL) is a calcium salt of natural lactate acid, which can be produced by lactic acid fermentation in the production of polylactic acid (PLA) (Xu & Xu, 2014). This white powder is a common source of calcium in food (Liao, Joshi, Tiwari, Park, & Kim, 2016). It has

Suan Sunandha Science and Technology Journal

been mostly used in food industries as firming agents and food additives. Recently, CL has been introduced in several fields, including polymer industries. Because of its biocompatibility, CL has also been introduced in biomedical applications (Hwang, Kim, Joshi, & Park, 2019; Pant et al., 2013). Pant et al. (2013) revealed that the incorporation of CL improved the biomimetic mineralization of polyamide-6 nanofibers for bone compatibility. Apart from the biomimetic mineralization and biocompatibility, CL also provided the enhancement of tensile strength as presented in the polycaprolactone/CL composites (Liao et al., 2016). Sedlarik et al. (2009) also reported the improved mechanical properties of polyvinyl alcohol/CL. To the best of the authors' knowledge, there are a few literatures regarding CL-based composites. A lack of information about the morphological, thermal, and mechanical properties of CL filled PP composites, encourages authors to provide the studies to evaluate the competitiveness of this renewable material as a filler for any applications. In order to use renewable filler, there are three main objectives; the mechanical property improvement, an expensive materials matrix replacement, and non-renewable filler phase in a composite reduction (Oliver-Ortega et al., 2018). However, CL is a hydrophilic material due to its polar carboxyl group (Hwang et al., 2019). On the other hand, PP is nonpolar. The difference in polarity between PP and CL causes the immiscibility of the two materials. In order to improve the adhesion between these two materials, the addition of coupling agent is necessary. Ideally, this coupling agent should have at least two different co-monomers in its structure, where each one is compatible with each blended homopolymer to enhance the compatibility between the neat PP and the CL (Abdelwahab, Misra, & Mohanty, 2019). According to the literature, maleic anhydride grafted polypropylene (MAPP) has been used to increase the interfacial adhesion between PP and fillers (Abdelwahab et al., 2019; Bikiaris, Vassiliou, Pavlidou, & Karayannidis, 2005). The polar anhydride group in MAPP has interaction with the filler surface. This interaction leads to better adhesion and hence the increase in stress transfer between the neat PP and fillers. Therefore, theoretically, the incorporation of MAPP should result in the improved adhesion between the PP and CL and consequently enhance the mechanical properties of the PP/CL composites.

The purpose of this work is to clarify the influence of calcium lactate as filler in PP composites and to study the morphological, thermal, and mechanical properties of these composites. To this end, the effect of MAPP as the coupling agent addition is also reported. The investigation includes melt flow index measurement, optical microscopy, differential scanning calorimetry and mechanical tests (tensile, flexural and impact tests). The novelty aspect of this work can be highlighted by the fact that this is one of the first studies to involve PP matrix composites with calcium lactate.

2. Experimental

2.1 Materials

HMC Polymer provided a commercial grade polypropylene (PP) (HP553R) and calcium lactate was purchased from PURAC. The particle size and shape of CL are revealed by the high resolution SEM micrographs as presented in Figure 1. The maleic anhydride grafted polypropylene (MAPP) with average M_w of 9,100 g/ mol and 8-10 wt% maleic anhydride content as coupling agent was supplied by Sigma Aldrich.

2.2 Preparation of composites

The neat PP and PP filled with various CL loadings (10-40 wt%) were first blended by melt compounding in an internal mixer (MX500, Chareon Tut) with a roller rotor speed of 60 rpm at 190°C for 20 minutes. In the selected PP/CL composite with optimal properties, MAPP was added in four different amounts, 2, 4, 6 and 8 wt%, based on the CL content. In order to get better CL particle dispersion in PP matrix, the compounds were then extruded via a co-rotating twin screw extruder (CTED22L32, Chareon Tut) with a screw speed of 60 rpm at the die temperature of 210°C. After extrusion, the extrudates were injected into a family mold (60SE, JONWAI) with a mold temperature of 40°C to produce the test specimens.

2.3 Melt flow index

Melt flow index (MFI) of neat PP and its composites was performed according to ASTM standard D1238 using melt flow indexer (MP1200, Tinius Olsen) with a weight of 2.16 kg at 230°C.

Suan Sunandha Science and Technology Journal

2.4 Optical properties

Thin section of 10 μm was prepared from the middle part of the injection molded specimen using manual rotary microtome (RM2235, Leica). The thin section was then immersed in oil between a glass slide and cover slip. The measurement was performed with a polarized optical microscope (DM2700M, Leica). A minimum of three sections was measured for each material.

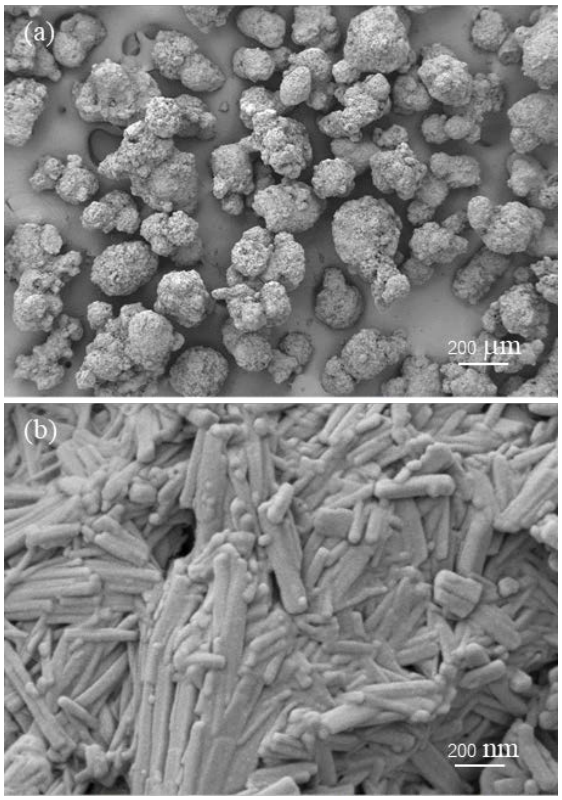

Figure 1. SEM micrographs of CL particles: (a) 50X, (b) 50000X.

2.5 Thermal properties

Thermal properties of all specimens were examined using differential scanning calorimetry (DSC, Q200, TA Instruments) equipped with the Refrigerated Cooling Systems 90 (RCS90). The samples with mass between 5 and 10 mg were placed in an aluminum pan and completely sealed with an aluminum lid. The measurements started with the heating scan with a ramp rate of 10°C/min from 0°C to 200°C and held at this temperature for 5 minutes. Then, the cooling scan was performed with a ramp rate of 10°C/min from 200°C to 0°C. The measurements were repeated for both heating and cooling scans with the same condition. The nitrogen was always purged during the measurements. The degree of crystallinity (X_c) was computed as follows:

$$X_c\,(\%) = \frac{100(\Delta H_m)/\Delta H_m^{\circ}}{\emptyset_{PP}}$$

where ΔH_m is the melting enthalpy, ΔH_m° is the theoretical heat of fusion for 100% crystalline PP (209 J/g) (Garcia et al., 2005), and $\emptyset_{PP}$ is the weight fraction of PP.

2.6 Mechanical properties

The tensile and flexural properties of the neat PP and all composites were performed using a universal testing machine (UTM, Model 25ST, Tinius Olsen). The tensile testing was measured according to ASTM standard D638 with a loading cell of 5 kN and a crosshead speed of 50 mm/min. The flexural testing was conducted according to ASTM standard D790 with a load cell of 1 kN and at a speed of 2 mm/min. According to ASTM standard D256, the notched Izod impact testing was tested using an impact tester (IT504, Tinius Olsen) with the hammer pendulum of 5.64 Jules. The 10 specimens were used for both the tensile, flexural and impact tests.

3. Results and Discussion

3.1 Effect of CL on the PP properties

Figure 2 presents the melt flow index (MFI) of PP filled with various CL loadings. The MFI is inversely proportional to the viscosity of polymer in the molten state. It is obvious that the MFI of PP composites decreases with an increase in the CL loading. The reduction in the MFI is in consequence with the rise in viscosity of the PP composites because of the restriction of molecular chain mobility imposed by the filler particles. Moreover, the presence of higher CL loading increases the possibility of the particle-particle contact and may lead to an increase in the flow resistance, thus the viscosity. This result agrees with previous studies that reported the same trend in PP and polyethylene composites (Escócio Pacheco, Silva, Cavalcante, & Visconte, 2015; Soleimani, Tabil, Panigrahi, & Opoku, 2008). The use of CL with high loading has a tendency to reduce the flowability of PP during processing, which might further limit the processability of the PP composites. However, Abdelwahab et al. (2019)

Suan Sunandha Science and Technology Journal

found a reduction in the MFI with the addition of coupling agent. It formed an interaction between polymer matrix and filler and helped to enhance the adhesion between the phases.

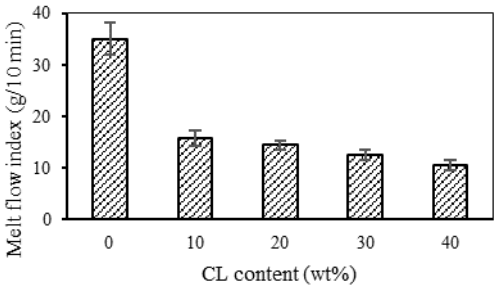

Figure 2. Melt flow index of neat PP and PP/CL composites.

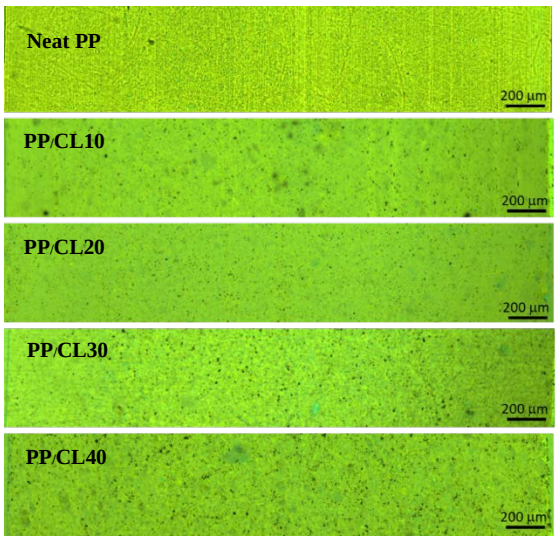

Figure 3. OM micrographs of neat PP and its composites.

Figure 3 represents the optical microscope (OM) images of materials where the CL particles (black spots) were in the PP matrix. The images were captured throughout the thickness of injection parts. These OM images reveal agglomerates of CL particles. The agglomerates become larger with increasing CL loading. This is reasonable considering that at high CL loadings, the interparticle distance become smaller, and hence the particles trend to form agglomerates.

Figure 4 reveals the spherulitic structure of neat PP and its composites. The micrographs were taken at the center of the thin section. It can be observed that the addition of CL leads to a reduction in the spherulite size, implying that CL particles or CL agglomerates act as nucleating site for PP crystallization. With the addition of CL, the higher density of nuclei provides the smaller spherulite size. However, at higher loading the agglomeration of CL particle is found, therefore the larger spherulite can be observed. A similar observation was reported by Palza et al. in PP/silica nanocomposites (Palza, Vera, Wilhelm, & Zapata, 2011).

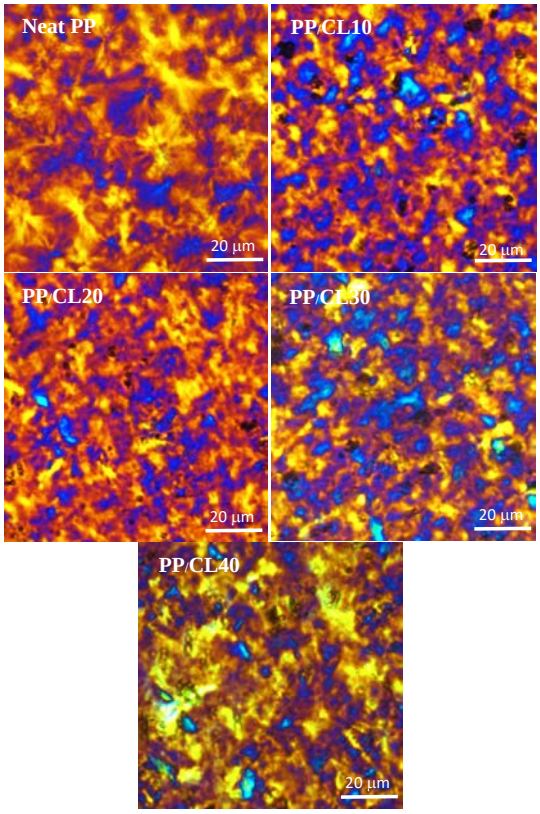

Figure 4. Spherulitic structure of neat PP and PP/CL composites.

The DSC thermograms of the second heating and cooling scans of neat PP and PP/CL composites are presented in Figure 5 and all DSC parameters are summarized in Table 1. A single peak at about 162°C during the second heating is attributed to the melting of α-crystal of neat PP (Padden & Keith, 1959). However, the T_m of PP remains almost constant in all composites. According to Table 1, the difference in the T_c of PP in all composites is significant compared to neat PP. The incorporation of CL increases the T_c of PP. The increase in T_c with increasing CL loading is also observed. The higher crystallization peak would suggest a faster crystallization in the PP/CL composites in comparison with neat PP. This is a

Suan Sunandha Science and Technology Journal

result of the CL particle acting as a heterogeneous nucleation site. The existence of foreign particle in the polymer melt reduces the energy needed to form a new surface and also reduces the nucleus size for crystal growth (Mucha, and Królikowski, 2003). This provides the faster nucleation rate, thus the overall crystallization rate.

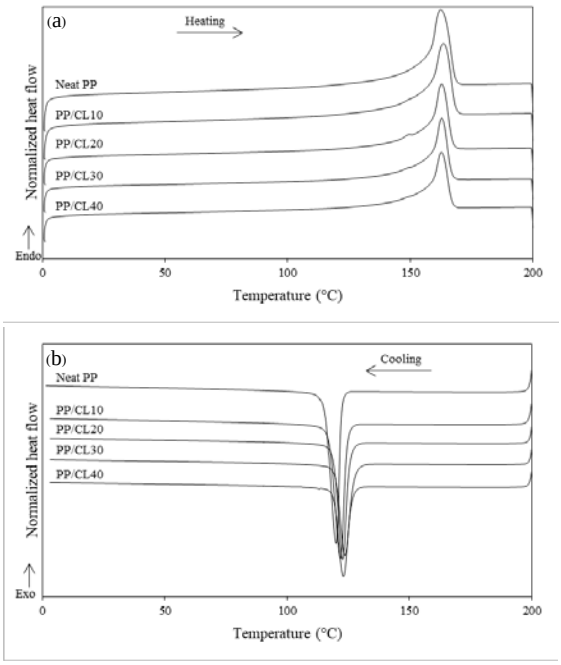

Figure 5. DSC thermograms of neat PP and its composites during (a) second heating and (b) cooling scans.

The degree of crystallinity (X_c) of neat PP was evaluated as 43.4%. It is obvious that the CL inclusion affects the X_c of PP as listed in Table 1. The X_c decreases with increasing CL loading. The addition of 10 wt%, 20 wt%, 30 wt% and 40 wt% CL to PP decreases the X_c considerably to 35.5%, 32.9%, 24.9% and 19.4%, respectively. The decrease in the X_c of PP is due to CL particles inhibiting the PP segment mobility and disrupting the PP chain structure regularity (Abdelwahab et al., 2019).

Table 1. DCS parameters of neat PP and CL filled PP composites.

Materials	T_c (°C)	T_m (°C)	ΔH_m (J/g)	X_m (%)
Neat PP	120.0	162.3	90.7	43.4
PP/CL10	121.9	163.6	82.4	35.5
PP/CL20	122.8	162.8	85.9	32.9
PP/CL30	123.8	162.9	74.4	24.9
PP/CL40	123.0	162.8	67.4	19.4

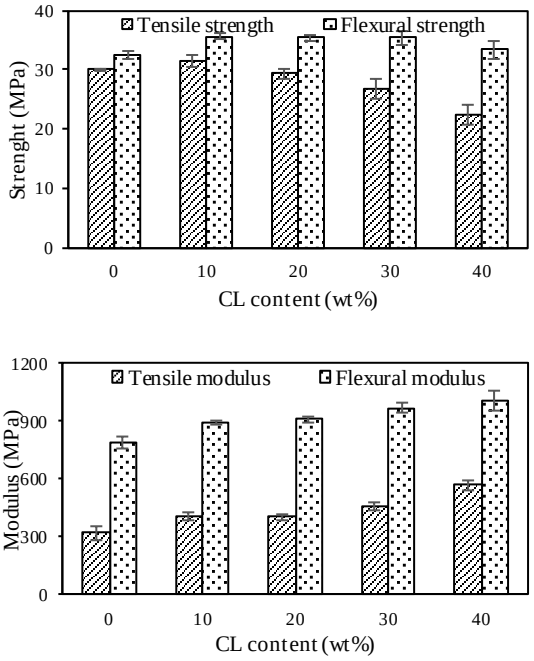

Figure 6. Mechanical properties of neat PP and CL filled PP composites (a) tensile and flexural strengths (b) tensile and flexural modulus.

Figure 6 illustrates the tensile and flexural properties of PP and its composites. It can be seen that the tensile and flexural strengths of PP increase with the incorporation of 10 wt% of CL. However, with further increase in the CL loading beyond 10 wt%, tensile and flexural strengths linearly decrease with the CL loading. At the higher filler loading, the distance between neighbor particles becomes smaller and tends to agglomerate (Altay et al., 2019), as observed in OM micrographs. Moreover, the difference in the polarity between PP matrix and CL leads to poor adhesion and hence the reduction in transfer stress between the neat PP and CL particles.

It can also be noticed from Figure 3 that the tensile and flexural moduli increase with the addition of CL. The moduli of PP increase with increasing CL loading. This is because of the higher modulus of filler particles (Altay et al., 2019). The increases in the modulus with filler loading is in accordance with other reported research (Das et al., 2016; Essabir et al., 2018; Mir et al., 2013).

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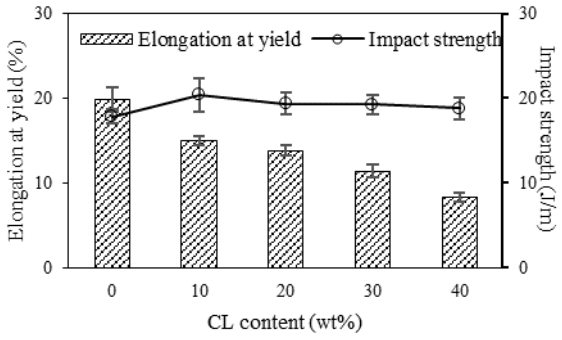

Figure 7. Elongation at break and impact strength of neat PP and PP/CL composites.

In the case of elongation at break, the results are as expected. The incorporation of CL causes a huge decrease in the elongation at break of PP as illustrated in Figure 7. Since the CL particles are rigid and have no elongation, they restrict the polymer molecules flowing past one another. It also seems that the reduction in the elongation of PP is a function of CL loading. As mentioned earlier, the formation of CL agglomeration can occur at higher CL loading. This agglomeration can act as stress concentration and breaking point of the composites (Bikiaris et al., 2005).

The notched Izod impact strength of neat PP and its composites is presented in Figure 6. It is clear that the impact strengths of the PP/CL composites are higher than that of neat PP. The smaller spherulite size of PP/CL composites may be responsible for the improvement of impact strength. The smaller spherulite size always accompanies the higher tie-molecules, improving the molecular entanglement between crystals lamellae. Thus, it leads to an increase of impact strength (Xu, Yu, & Jin, 2001). In addition, the impact strength of PP is independent of CL loading. Based on the tensile, flexural and impact properties of PP, the optimum loading of CL is 10 wt%. This composition was chosen for the study of the influence of the coupling agent addition in the following section.

3.2 Effect of MAPP on the PP/CL composite properties

The effect of MAPP on the MFI of PP composites is shown in Figure 8. MAPP slightly increases the MFI of the composites when compared with composite without coupling agent. An increase in the MFI is in consequence with the decrease in the viscosity of PP composites. There are two possible explanations for this phenomena. The first one is that MAPP acts as an internal lubricant to aid the PP chain motion. The MAPP may help to enhance the intermolecular free volume between polymer chains, thus reducing the polymer viscosity (Poletto, 2018). The second reason may be associated with the migration of the MAPP toward the composite surface. This forms a slip in the composite layers to the die, resulting in an increase in the MFI (Poletto, 2018).

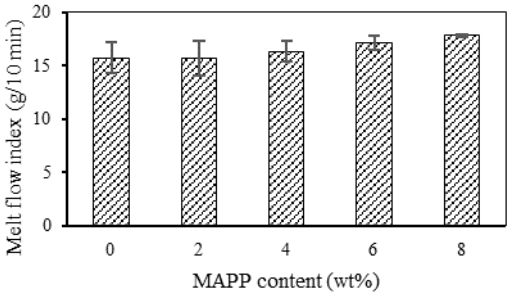

Figure 8. Melt flow index of PP composites filled with MA.

For effective improvement of mechanical properties, strong interfacial adhesion between PP and CL particles is necessary. Although an enhancement in the tensile strength and modulus of PP is expected due to better adhesion between PP matrix and CL particles using MAPP, this however, is not the case. Concerning the effect of the addition of MAPP, it appears that it has a negative effect on both the tensile strength and the modulus as presented in Figure 9 (a). The addition of MAPP coupling agent exhibits a small decrease on both tensile properties of PP. The results of elongation at break are shown in Figure 9 (b). An increase of elongation at break can be observed with addition of MAPP. The maximum elongation is at the MAPP loading of 6 wt%. It also can be observed from the Figure 9 (b) that the impact strength of PP/CL composites are independent of MAPP content. These unexpected results may be caused by several factors: (i) the deterioration of MAPP during the processing, (ii) no interaction between MAPP as the MAPP migrate to the composite surface and CL, (iii) MAPP act as lubricant for PP composites.

Suan Sunandha Science and Technology Journal

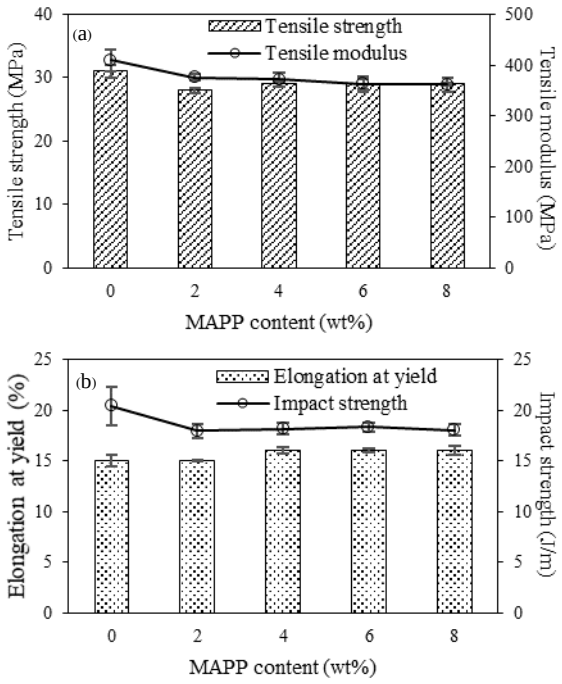

Figure 9. Mechanical properties of PP/CL composites with addition of MAPP (a) tensile strength and modulus (b) elongation at break and impact strength.

4. Conclusion

This work aimed to study the effect of calcium lactate addition in PP composites. PP composites were prepared with different amount of calcium lactate (0, 10, 20, 30, and 40 wt%) using melt mixing and injection molding. Morphological, thermal, and mechanical properties of the PP/calcium lactate composites were characterized. The addition of increasing calcium lactate content (up to 40 wt%) to neat PP continuously enhanced the tensile/flexural moduli of the composites. The maximum value of the tensile/flexural strengths and impact strength were found at 40 wt% calcium lactate loading. However, when neat PP was added with calcium lactate, a decrease in elongation at break was found in the composites. Furthermore, the presence of calcium lactate provided the smaller spherulite size, faster crystallization initiation, but lower degree of crystallinity as compared to neat PP. It can be drawn from the investigation that the resulting properties of the composites was a result of a competition effect between the interfacial adhesion of two phases and the morphological structure of the composites. In addition, the use of coupling agent offered insignificant mechanical improvements in this work.

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6. Publication Ethic

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7. References

Abdelwahab, M. A., Misra, M., & Mohanty, A. K. (2019) . Injection molded biocomposites from polypropylene and lignin: Effect of compatibilizers on interfacial adhesion and performance. *Industrial Crops and Products, 132*, 497-510. doi: 10. 1016/ j. indcrop. 2019. 02.026

Altay, L., Atagur, M., Sever, K., Sen, I., Uysalman, T., Seki, Y., & Sarikanat, M. (2019). Synergistic effects of graphene nanoplatelets in thermally conductive synthetic graphite filled polypropylene composite. *Polymer Composites*, *40*(1), 277-287. doi:10.1002/pc.24643

Bikiaris, D. N., Vassiliou, A., Pavlidou, E., & Karayannidis, G. P. (2005). Compatibilisation effect of PP-g-MA copolymer on iPP/SiO_2 nanocomposites prepared by melt mixing. *European Polymer Journal*, *41*, 1965-1978. doi:10.1016/j.eurpolymj.2005.03.008

Bledzki, A. K., Franciszczak, P., Osman, Z., & Elbadawi, M. (2015). Polypropylene biocomposites reinforced with softwood, abaca, jute, and kenaf fibers. *Industrial Crops and Products*, *70*, 91-99. doi:10.1016/j.indcrop. 2015.03.013

Das, O., Bhattacharyya, D., Hui, D., & Lau, K.-T. (2016). Mechanical and flammability characterisations of biochar/polypropylene biocomposites. *Composites Part B, 106*, 120-128. doi:10.1016/j.compositesb.2016.09.020

Escócio, V. A., Pacheco, E. B. A. V., Silva, A. L. N., Cavalcante, A. P., & Visconte, L. L. Y. (2015). Rheological behavior of renewable polyethylene (HDPE) composites and sponge

Suan Sunandha Science and Technology Journal

gourd (*Luffa cylindrica*) residue. *International Journal of Polymer Science, 2015*. doi:10.1155/2015/714352

Essabir, H., Raji, M., Laaziz, S. A., Rodrique, D., Bouhfid, R., & Qaiss, A. E. K. (2018). Thermo-mechanical performances of polypropylene biocomposites based on untreated, treated and compatibilized spent coffee grounds. *Composites Part B, 149*, 1-11. doi:10.1016/j.compositesb.2018.05.020

Garcia, M., van Vliet, G., Jain, S. , Schrauwen, B. A. G., Sarkissov, A., van Zyl, W. E., & Boukamp, B. A. (2005). Polypropylene/SiO_2 nanocomposites with improved mechanical properties. *Reviews on Advanced Materials Science*, *6*(2), 169-175.

Hwang, T. I., Kim, J. I., Joshi, M. K., & Park, C. H. (2019). Simultaneous regeneration of calcium lactate and cellulose into PCL nanofiber for biomedical application. *Carbohydrate Polymers*, *212*, 21-29. doi:10.1016/j.carbpol. 2019.01.085

Liao, N., Joshi, M. K., Tiwari, A. P., Park, C. H., & Kim, C. S. (2016). Fabrication, characterization and biomedical application of two-nozzle electrospun polycaprolactone/zein-calcium lactate composite nonwoven mat. *Journal of the Mechanical Behavior of Biomedical Materials*, *60*, 312-323. doi:10.1016/j.jmbbm.2016.02.006

Mir, S. S., Nafsin, N., Hasan, M., Hasan, N., & Hassan, A. (2013). Improvement of physico-mechanical properties of coir-polypropylene biocomposites by fiber chemical treatment. *Materials and Design*, *52*, 251-257. doi:10.1016/j.matdes.2013.05.062

Mucha, M. & Krolikowski, Z. J. (2003). Application of DSC to study crystallization kinetics of polypropylene containing fillers. Journal of Thermal Analysis and Calorimetry , 74(2),549-557. doi.org/10.1023/B:JTAN.0000005193.66789.ea

Oliver-Ortega, H., Chamorro-Trenado, M. A., Soler, J., Mutjé, P., Vilaseca, F., & Espinach, F. X. (2018). Macro and micromechanical preliminary assessment of the tensile strength of particulate rapeseed sawdust reinforced polypropylene copolymer biocomposites for its use as building material. *Construction and Building Materials*, *168*, 422-430. doi:10.1016/j.conbuildmat.2018.02.158

Padden, F. J., & Keith, H. D. (1959). Spherulitic crystallization in polypropylene. *Journal of Applied Physics*, *30*, 1479. doi:10.1063/1. 1734985

Palza, H., Vera, J., Wilhelm, M., & Zapata, P. (2011). Spherulite growth rate in polypropylene/silica nanoparticle composites: Effect of particle morphology and compatibilizer. *Macromolecular Materials and Engineering*, *296*(8), 744-751. doi:10.1002/mame.201000405

Pant, H. R., Risal, P., Park, C. H., Tijing, L. D., Jeong, Y. J., & Kim, C. S. (2013). Synthesis, characterization, and mineralization of polyamide-6/calcium lactate composite nanofibers for bone tissue engineering. *Colloids and Surfaces B: Biointerfaces*, *102*, 152-157. doi:10.1016/j.colsurfb.2012.08.032

Poletto, M. (2018). Influence of coupling agents on rheological, thermal expansion and morphological properties of recycled polypropylene wood flour composites. *Maderas: Ciencia y Tecnología*, *20*(4), 563-570. doi:10.4067/S0718-221X2018005004401

Sedlarik, V., Galya, T., Emri, I., & Saha, P. (2009). Structure and conditioning effect on mechanical behavior of poly (vinyl alcohol)/calcium lactate biocomposites. *Polymer Composites*, *30*(8), 1158-1165. doi:10.1002/pc.20672

Soleimani, M., Tabil, L., Panigrahi, S., & Opoku, A. (2008). The effect of fiber pretreatment and compatibilizer on mechanical and physical properties of flax fiber-polypropylene composites. *Journal of Polymers and the Environment*, *16*, 74-82. doi:10.1007/s10924-008-0102-y

Xu, K., & Xu, P. (2014). Efficient calcium lactate production by fermentation coupled with crystallization-based in situ product removal. *Bioresource Technology*, *163*, 33-39. doi:10.1016/j.biortech.2014.04.002

Xu, T., Yu, J., & Jin, Z. (2001). Effects of crystalline morphology on the impact behavior of polypropylene. *Materials and Design*, *22*, 27-31. doi:10.1016/S0261-3069(00)00033-9

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WNN : File Format for Neural Network Interchange

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Abstract

A programming language agnostic, neural network library agnostic, standardized file format used to save an already trained neural network model would facilitate the process of sharing or releasing said neural network model online in a simplistic fashion. A standard file format for saving neural network models would include metadata about the neural network such as the number of inputs, hidden layers, nodes per hidden layer, outputs and the activation function used along with the weights and bias values. Such a file can be parsed to reconstruct a neural network model in any programming language or library and would remove a neural network model's dependency on the library it was created on.

Keywords: Artificial neural networks, File format, Neural network model sharing, Neural network model saving

1. Introduction

Due to the recent spike in interest resulting from the developments in the fields of Artificial Intelligence and Machine Learning, there has been no shortage of neural network libraries such as TensorFlow by Google, PyTorch by Facebook, Keras, DeepLearning4J, OpenNN, FANN, and much more (Erickson, Korfiatis, Akkus, Kline, & Philbrick, 2017).

The ability to save a trained neural network model on disk for reuse is provided by all major neural libraries but each library uses its own approach to save a neural network model and they are incompatible with each other. This hinders advancements in the machine-learning field as it imposes restrictions on how much a neural network model can be shared between users. This is analogous to designing a webpage that will only load as intended on one web browser and will fail to load on all other browsers.

1.1 Neural networks at their core

A neural network, at its core, is described as a universal function approximator (Hornik, Stinchcombe, & White, 1989; Poggio & Girosi, 1990). It can be represented as a collection of floating-point numbers, along with some metadata. A neural network is defined by its constituent weight and bias values, and anything else that has to do with a neural network (such as the ability to feed forward the input values and obtain an output) is up to the implementation.

Thus, a file that contains the weights and bias values, along with some important header information such as the number of inputs, number of outputs, number of hidden layers, number of nodes per hidden layer and the employed activation function (sigmoid, ReLU, tanh, etc.) can be used to reconstruct a neural network in the language or neural network library of the user's choice.

1.2 History and background information

The idea of artificial neural networks was first conceived by Warren McCulloch and Walter Pitts (McCulloch & Pitts, 1943) who created a computational model for artificial neural networks based on algorithms called threshold logic. Breakthroughs in the field of computer science that made use of artificial neural networks include the creation of the perceptron in 1958 by Frank Rosenblatt (Rosenblatt, 1958) and the formulation of the backpropagation algorithm in 1986 (Rumelhart, Hinton, & Williams, 1986).

1.3 Notations and terminology

Superscript – denotes the layer of the neural network

Subscript – denotes the specific node in a layer (starting with 0 at the top)

w – denotes the weight between two nodes

b – denotes the bias value of the node

2. The Proposed Format

WNN (**W**eights of **N**eural **N**etwork) is the proposed file format whose intended use is to save neural network models in a programming language and neural network library agnostic way.

A WNN file can be downloaded from a neural network repository or obtained through a

Suan Sunandha Science and Technology Journal

CDN and can be parsed* to recreate a functioning neural network model without the need to train the neural network again.

The wnn file will consist of three parts –

- Header Information
- Weight Values
- Bias Values

Header Information

The file must begin by listing the following information in order, separated by a line break –

- Number of Inputs
- Number of Hidden Layers
- Number of Nodes in each Hidden Layer
- Number of Outputs
- Employed activation function for each layer

The number of nodes in each hidden layer should be listed in the same line, separated by spaces. If all hidden layers have the same number of nodes, listing that number once should suffice.

The employed activation function should be represented by a single-digit integer, ranging from 0 to 7, according to the given table –

Value	Activation Function
0	Sigmoid
1	Tanh
2	Arctan
3	Softmax
4	Softplus
5	ReLU
6	Leaky ReLU
7	ELU

In case the activation function being employed is Leaky ReLU($y = \max(\boldsymbol{\alpha x}, \mathbf{x})$) or the ELU$\left(y = \begin{cases} \boldsymbol{\alpha}(\mathbf{e^x - 1}), & x < 0 \\ x, & x \geq 0 \end{cases}\right)$, the $\boldsymbol{\alpha}$ value must be listed with the activation function index separated by a whitespace.

The Weight Values

Following the header information, separated by a line feed, will be the value of the weights of the connections between each node.

Let w_{ij}^{L} be a weight value of the connection between nodes of index i and j in the layers L and L+1 respectively (Clarkson, 1996).
Let m be the number of nodes in the preceding layer and n be the number of nodes in the succeeding layer.

The weights of the same layer should be listed as a group, separated by spaces, and each group of weights per layer should be separated by line feeds as follows –

$$w_{00}^{0}\ w_{01}^{0}\ w_{02}^{0}\ \dots\ w_{0(n-1)}^{0}\ w_{10}^{0}\ w_{11}^{0}\ w_{12}^{0}\ \dots\ w_{(m-1)(n-1)}^{0}$$
$$w_{00}^{1}\ w_{01}^{1}\ w_{02}^{1}\ \dots\ w_{0(n-1)}^{1}\ w_{10}^{1}\ w_{11}^{1}\ w_{12}^{1}\ \dots\ w_{(m-1)(n-1)}^{1}$$
$$\vdots$$
$$w_{00}^{L}\ w_{01}^{L}\ w_{02}^{L}\ \dots\ w_{0(n-1)}^{L}\ w_{10}^{L}\ w_{11}^{L}\ w_{12}^{L}\ \dots\ w_{(m-1)(n-1)}^{L}$$

The Bias Values

Let b_i^L be the bias of the i[th] node in the L[th] layer of the neural network. Let m be the number of nodes in the corresponding layer. The biases of each node in a layer should be listed in a line, separated by spaces, and each layer should be separated by a line feed as follows –

$$b_0^0\ b_1^0\ b_2^0\ \dots\ b_{(m-1)}^0$$
$$b_0^1\ b_1^1\ b_2^1\ \dots\ b_{(m-1)}^1$$
$$\vdots$$
$$b_0^L\ b_1^L\ b_2^L\ \dots\ b_{(m-1)}^L$$

Sample WNN file and parser can be found at https://www.github.com/anirudhgiri/WNN-File-Parser

Suan Sunandha Science and Technology Journal

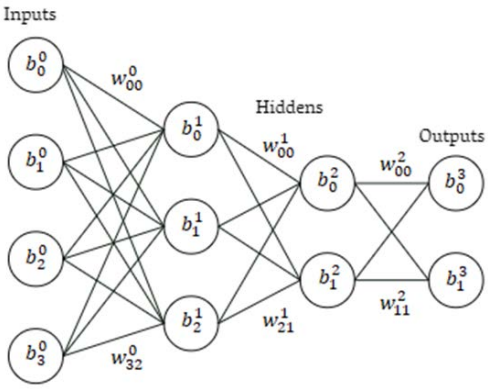

Figure 1. A sample neural network with the correct notations for reference.

3. Examples and Experimentation

Taking a neural network model with 2 inputs, 2 hidden layers with 2 nodes in the first hidden layer and 1 node in the second hidden layer and 2 outputs where all layers use the ReLU activation function (except the output layer, which uses the softmax function) and where all the weights and biases are set to 0, the resulting WNN file was generated as follows -

```
2
2
2 1
2
5 5 5 3
0 0 0 0
0 0
0 0
0 0
0 0
0
```

Another wnn file for a deep neural network model to simulate the XOR function was generated**.** The WNN file was as follows –

```
2
1
2
1
0
13.83 13.83 15.31 15.31
-11.52 11.52
-19.35 -6.78
-5.13
```

The model consisted of 2 inputs, 1 hidden layer, 2 nodes in the hidden layer and 1 output where all layers used the sigmoid activation function**.**

4. Results and Discussions

The parser was successfully able to retrieve enough information from both files to be able to rebuild the artificial/deep neural network model which their respective wnn file was describing**.**

```
Number of Inputs : 2
Number of Hidden Layers : 2
Number of Nodes in layer 1 : 2
Number of Nodes in layer 2 :
Number of Nodes in layer 3 : 1
Number of Outputs : 2
Activation Function Used In Layer 0 : ReLU
Activation Function Used In Layer 1 : ReLU
Activation Function Used In Layer 2 : ReLU
Activation Function Used In Layer 3 : Softmax
Weight values :
0 0 0 0
0 0
0 0
Bias Values:
0 0
0 0
0
```

Figure 2. The output of the parser program when it was served with the example wnn file listed in section 4.

```
Number of Inputs : 2
Number of Hidden Layers : 1
Number of Nodes Per Hidden Layer : 2
Number of Outputs : 1
Activation Function Used (For all layers) : Sigmoid
Weight values :
13.83 13.83 15.31 15.31
-11.52 11.52
Bias Values:
-19.35 -6.78
-5.13
```

Figure 3. The output of the parser program when it was served with the example WNN file listed in section 4.

5. Scope for the Future

A standard file format, if used by all major neural network libraries to save models and load them with their own parsers, would be greatly beneficial to the field of artificial intelligence and machine learning**.** It could give rise to a centralised repository for neural network models hosted on the cloud where machine learning engineers can

Suan Sunandha Science and Technology Journal

collaborate to create the most efficient models for all sorts of use cases**.**

Neural network models with high prediction accuracies could be searched for online through a catalogue instead of training them from scratch every time they are needed**.** It would be similar to using open source libraries from GitHub instead of writing the code from scratch every time certain functionalities need to be added**.**

Software similar to package managers like npm and pip could be created to access and download neural network models through the command line on demand**.**

6. Conclusion

This paper has described the need for a standardized file format for neural network models, the advantages of having the format, and the potential applications that can be created to use the format to facilitate the sharing of neural network models over the internet**.**

This paper has also outlined the specifications of such a file format**.** While the proposed format is not perfect, has drawbacks **(**such as its inefficiency in storing the topology of networks where two adjacent layers are not complete graphs**)** and is not universal as it does not cover some exotic neural network types, WNN is a start and can be used as a foothold to build a truly universal and maximally efficient format**.**

7. References

Clarkson, T. G. (1996). Introduction to neural networks. *Neural Network World*, *6*(2), 123-130. doi:10.1201/9781482277180-13

Erickson, B. J., Korfiatis, P., Akkus, Z., Kline, T., & Philbrick, K. (2017). Toolkits and libraries for deep learning. *Journal of Digital Imaging*, *30*(4), 400-405. doi:10.1007/s10278-017-9965-6

Hornik, K., Stinchcombe, M., & White, H. (1989). Multilayer feedforward networks are universal approximators. *Neural Networks*, *2*(5), 359-366. doi:10.1016/0893-6080(89)90020-8

McCulloch, W. S., & Pitts, W. (1943). A logical calculus of the ideas immanent in nervous activity. *The Bulletin of Mathematical Biophysics*, *5*, 115-133. doi:10.1007/BF02478259

Poggio, T., & Girosi, F. (1990). Networks for approximation and learning. *Proceedings of the IEEE*, *78*(9), 1481-1497. doi:10.1109/5.58326

Rosenblatt, F. (1958). The perceptron: A probabilistic model for information storage and organization in the brain. *Psychological Review*, *65*(6), 386-408. doi:10.1037/h0042519

Rumelhart, D. E., Hinton, G. E., & Williams, R. J. (1986). Learning representations by back-propagating errors. *Nature*, *323*(6088), 533-536. doi:10.1038/323533a0

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Germination and Early Life Stage Development of Lettuce and Carrot upon Exposures to Dissolved Microcystins

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Abstract

Cyanobacterial mass development and their toxins have become an environmental issue recently. In this study, we tested the effects of two crude extracts contained microcystins (MC), including an isolated *Microcystis aeruginosa* and a water blooms sample collected from Dau Tieng Reservoir, Vietnam, on the seed germination, root and shoot prolongation and wet weight (WW) during the seedling of lettuce and carrot. The MC concentrations were environmentally relevant, 1-100 µg/L and the experimental period lasted for 7 days. We found that both lettuce and carrot seeds were suffered from the MC impact with a lower germination rate compared to control. After 4 and 7 days of the experiment, the root and shoot of both plants were shorter upon MC incubation and the higher MC concentration applied, the shorter length of root and shoot was. The WW of lettuce and carrot seedling was significantly reduced in exposures to MC at the concentrations of 10 and 100 µg/L. This study confirmed the potent toxicity of MC from Vietnam waters at the environmental concentrations to lettuce and carrot. Bioaccumulation and distribution of MC in the plants are suggested to investigate in the future.

Keywords: Cyanobacterial toxins, Seedling, Exposure, Impacts

1. Introduction

Freshwater bodies in the world have commonly been under eutrophic conditions (Chorus & Bartram, 1999) which would be consequently on the mass development of cyanobacteria. Besides, bloom forming of cyanobacteria has been enhanced frequently and intensity upon the climate change context (Paerl & Huisman, 2009). Cyanobacteria could gain nearly 100% of phytoplankton biomass during their blooms (Vasconcelos & Pereira, 2001) and they are usually associated with cyanobacterial toxin occurrence (Zurawell, Chen, Burke, & Prepas, 2005). Microcystins (MC) are among the most common and potent cyanobacterial toxins (e.g. MC, anatoxin-a, cylindrospermopsin, saxitoxins) in inland aquatic ecosystems. Their concentrations in water could be very high, some hundred µg MC/L in dissolved form or even up to several mg/L in bloom materials. The toxins could induce a wide range of impacts on aquatic plants, animals and human beings (Chorus & Bartram, 1999).

Surface water from rivers, lakes, and reservoirs could be used for multi-purposes such as drinking water supplies, aquaculture and agricultural activities. Codd (1999) reported that the cyanobacterium *Microcystis aeruginosa* and its toxin (MC) were retained by lettuce after spraying with irrigation water containing the toxic cyanobacterium. In line with this study, McElhiney Lawton, and Leifert (2001) found the plant growth was inhibited when watered with cyanobacterial extract containing MC. Similarly, the growth and development of different plants such as rice, rapeseed, mustard, duckweed were negatively affected by MC (Chen, Song, Dai, Gan, & Liu,

Suan Sunandha Science and Technology Journal

2004; Kurki-Helasmo & Meriluoto, 1998; Mitrovic, Allis, Furey, & James, 2005). Incubation in MC (either from purified or extracted material) resulted in a reduction of seed germination, root and shoot length and leaf shape of spinach, rapeseed and tomato (Al-Sultan & Hatem, 2019; Chen et al., 2004; Dao, Le, Pham, Do-Hong, & Nguyen, 2014; Pflugmacher, Aulhorn, & Grimm, 2007). Previous investigations noted that the fresh weight of plants (e.g. rice and rapeseed) exposed to MC was reduced (Chen et al., 2004; Dao et al., 2014). Besides, cyanobacterial toxins (MC, anatoxin-a) could cause a decrease of pigments in plants (Al-Sultan & Hatem, 2019; McElhiney et al., 2001; Weiss, Liebert, & Braune, 2000), consequently photosynthesis inhibition (Pietsch et al., 2001; Wiegand, Peuthert, Pflugmacher, & Carmeli, 2002). The cyanobacterial toxins could strongly regulate the antioxidant and biotransformation enzyme activities in plants (Ha & Pflugmacher, 2013; Pflugmacher et al., 2007).

In Vietnam, surface-water inland has been exploited for domestic use and farming. Toxic cyanobacteria, cyanobacterial blooms and their toxins (MC) have been reported widely (Dao, Cronberg, Nimptsch, Do-Hong, & Wiegand, 2010; Dao et al., 2014; Duong et al., 2013; Pham, Dao, Shimizu, Do-Hong, & Utsumi, 2015; Pham et al., 2017). Biomass of harmful cyanobacteria in water bodies (e.g. Tri An Reservoir) tends to increase spatially and temporally during the latest years (Nguyen, Ha, & Pham, 2020). Plants could be irrigated with water containing cyanobacteria and their toxins during farming. Therefore, we raised a question if the germination and seedling of the lettuce and carrot, which are commonly planted and consumed from Central Highland of Vietnam, are affected by MC at the environmental concentrations (1-100 µg/L) from Vietnam waters.

2. Materials and Methods

2.1 Materials

The seeds of lettuce (*Lactuca sativa* L.) and carrot (*Dacus carota* L.) were purchased from Trang Nong Company, located in District 6, Hochiminh City. The two cyanobacterial materials were used for experiment including (i) cyanobacterial scum (mainly *Microcystis* spp.) collected in July 2011 and (ii) the cyanobacterial isolate *Microcystis aeruginosa* from Dau Tieng Reservoir.

Crude extract from cyanobacterial scum and the isolate was prepared according to Pietsch et al. (2001) with minor modification. Briefly, 5 g of the dried biomass of cyanobacterial scum and isolate on GF/C filters was homogenized, suspended into 100 mL reversed osmosis water, sonicated, frozen at –70°C overnight and thawed at room temperature. The freeze/thaw cycle was repeated five times. After the last thawing cycle, samples were centrifuged at 4500 rpm, 4°C for 15 min. Supernatant was collected and kept at –70°C prior to experiments on the plant seedlings. The cyanobacterial scum material (Scum) contained around 687 µg MC/g dried mass (Dao et al., 2014), and the cyanobacterial isolate (*M. aeruginosa*, Ma) had a MC production of 3,733 µg/g dried mass (Vo, Pham, & Dao., 2016). Therefore, two cyanobacterial extracts, so-called mother solutions, from the scum material has a MC concentration of 34,350 µg/L, and that from the isolate has a MC concentration of 186,650 µg/L. To get the concentrations of around 1, 10 and 100 µg MC/L for the experiment, we diluted the mother solution with distilled water. We took 2.91 mL, 291 µL, and 29 µL of mother solution from scum material and filled with distilled water to a total volume of 1 liter, to make final MC concentrations of around 100 µg/L, 10 µg/L and 1 µg/L, respectively. Similarly, we took 536 µL, 54 µL, and 5.4 µL of mother solution from isolate and filled with distilled water to a total volume of 1 liter, to make final MC concentrations of around 100 µg/L, 10 µg/L and 1 µg/L, respectively.

2.2 Experimental setup

The experimental setup to test the seedling of lettuce and carrot was conducted according to Chen et al. (2004) and Dao et al. (2014) with minor modification. We did the same experimental design for seeds of carrot and lettuce. For the first experiment, the germination investigation, 50 seeds of either lettuce or carrot were placed onto paper

Suan Sunandha Science and Technology Journal

tissue put in a glass petri disc (10 cm in diameter) and three replicates (n = 3) were prepared for each treatment. In the control, the seeds were watered with 10 mL of distilled water. However, in the MC exposures, the seeds were treated with 10 mL of cyanobacterial extract from either scum sample or *M. aeruginosa* (cyanobacterial isolate) containing around 1, 10 and 100 µg MC/L. Therefore, in each kind of seed (lettuce or carrot) there were 7 treatments including (1) control, (2) around 1 µg MC/L from scum sample (abbreviated as Scum-1), (3) around 10 µg MC/L from scum sample (abbreviated as Scum-10), (4) around 100 µg MC/L from scum sample (abbreviated as Scum-100), (5) around 1 µg MC/L from the isolate *M. aeruginosa* (abbreviated as Ma-1), (6) around 10 µg MC/L from the isolate *M. aeruginosa* (abbreviated as Ma-10), and (7) around 100 µg MC/L from the isolate *M. aeruginosa* (abbreviated as Ma-100). The seed germination, defined as the root appearance from the seeds, in each treatment were counted after 24 h for lettuce and 72 h for carrot. Experiments were run at 25±1ºC, with the humidity of 75%, and in the dark.

The germinated seeds (seedling) in the petri discs from the first experiment were used for the second experiment on the root, shoot and wet weight development of lettuce and carrot. They were transferred onto tissue paper located in 100 mL glass beakers. Three replicates (n = 3) for each treatment, and 10 germinated seeds were put into a beaker. The seedlings were daily watered with 3 mL of distilled water (in control) or water containing around 1, 10, 100 µg MC/L from either scum sample or isolate, as mentioned in detail above. The tests were incubated at 25 ± 1ºC and the humidity of 75%, light intensity of around 1500 Lux, and 12 h light followed by 12 h dark cycle. The WW, shoot length and root length of the seedlings were recorded at 4 and 7 days of incubation. The WW was determined using a balance (Sartorius BP 201S, Germany) and the length was measured with a ruler of 1 mm spacing.

2.3 Data treatment

The germination rate of lettuce and carrot seeds was calculated by the ratios of the germinated seeds over the 50 seeds used for each treatment.

Sigmaplot, version 12.0 was used for data analysis. Kruskal-Wallis test was applied to determine the statistically significant differences of the WW, shoot and root length of seedlings in control and cyanobacterial extract treatments.

3. Results and Discussion

3.1 Germination of the lettuce and carrot seeds upon treatments with MC-containing cyanobacterial extracts

The germination rate of the lettuce and carrot seeds was shown in the Table 1. The rate in two controls, lettuce and carrot seeds, was 94% and 93%, respectively. In the treatments with the cyanobacterial extract from *M. aeruginosa* (Ma-1, Ma-10 and Ma-100), the rate varied between 81-87% for lettuce, and 59-85% for carrot. Besides, the treatments with an extract from the cyanobacterial scum (Scum-1, Scum-10 and Scum-100), the germination rate of lettuce was from 80-90%, and that of carrot was from 69-79% (Table 1). The higher microcystin concentration in the treatment it was, the lower germination rate of the plants (lettuce and carrot) it was. At the same toxin concentration from two different sources of MC (scum sample and isolate), the seed germination rate was similar. However, the germination rate of carrot was lower than that of lettuce when the seeds were treated with the same kind and concentration of MC.

Chen et al. (2004) found that the germination rate of rapeseed exposed to 0.6 µg MC/L was significantly lower than that in the control. This previous finding supported our record, evidencing the germination influence by the MC from the concentration of 1 µg/L. Mackintosh et al. (1990) reported that MC could inhibit the enzyme activities (e.g. protein phosphatases 1 and 2A) in plants. During germination, many biochemical processes are happening in seeds and also cellular division. Exposure to MC would result in dephosphorylating the regulatory proteins (Mackintosh et al., 1990), hence germination of the seeds could be delayed. Our study contributes the toxicity information from the cyanobacterial toxins from Vietnam waters to the germination of the seeds of plants carrot and lettuce.

Table 1. The seed germination rate of lettuce and carrot. Numbers expressed the mean values and standard deviations of n = 30. Different letters (a- e) indicated a significant difference of $p < 0.05$ by Kruskal-Wallis test.

Suan Sunandha Science and Technology Journal

Treatments	MC concentrations (µg/L)	Germination rate (%)	
		lettuce	carrot
Control	0	$94 \pm 1,2^{e}$	$93 \pm 1,7^{e}$
Extract from isolate (*M. aeruginosa*)	1	$87 \pm 1,7^{cd}$	$85 \pm 1,7^{d}$
	10	$81 \pm 1,7^{ab}$	$80 \pm 1,2^{cd}$
	100	$82 \pm 1,2^{ab}$	$59 \pm 1,7^{a}$
Extract from cyanobacterial scum (Scum)	1	$90 \pm 1,2^{de}$	$79 \pm 1,7^{c}$
	10	$85 \pm 1,3^{bc}$	$77 \pm 1,7^{c}$
	100	$80 \pm 1,2^{a}$	$69 \pm 0,6^{b}$

3.2 Root and shoot length of the lettuce and carrot upon treatments with MC-containing cyanobacterial extracts

After 4 days of the experiment, the root length of lettuce and carrot in the control was around 17.7 and 29.6 mm, respectively. However, the root of lettuce in the treatments with the extracts from isolate and scum material ranged from 15.9-16.6 mm, and 11.3-13.6 mm, respectively (Figure 1a). The root length of carrot in the Ma and Scum treatments was from 20.9-26.6 mm and 21.4-26.2 mm, respectively (Figure 1c). The length of root in treatment was significantly shorter than that in the control ($p < 0.05$; Kruskal-Wallis test).

After 7 days of the experiment, lettuce root in MC treatments (Ma and Scum) was from 17.4-26.9 mm long which was significantly different ($p < 0.05$) from that in the control, 28.2 mm (Figure 1b; Figure 2). A similar phenomenon, significant difference ($p < 0.05$), was observed with root length of carrot in MC incubations (30.9-45.8 mm) and the control (51.1 mm; Figure 1d). Besides, we found that the higher toxin concentrations in exposure, the lower root length of the seedlings of both lettuce and carrot was observed. Hence the negative effect seemed to be concentration dependent.

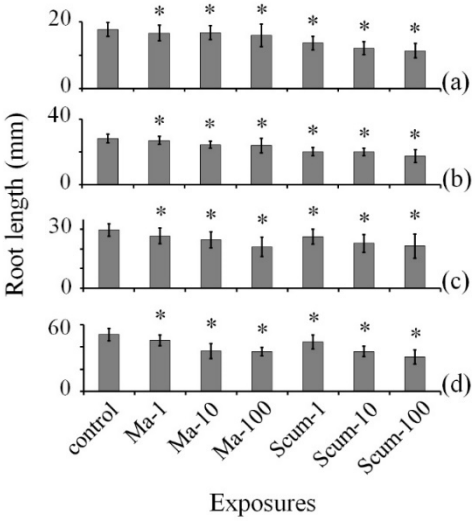


Figure 1. Root length of lettuce at 4 days (a) and 7 days (b), and of carrot at 4 days (c) and 7 days (d) of incubation. Ma and Scum are treatments with an extract from *M. aeruginosa* and cyanobacterial scum, respectively. Numbers (1, 10, 100) right after Ma and Scum revealed the MC concentrations as µg/L. The asterisks indicated the significant difference ($p < 0.05$) between control and exposures by Kruskall-Wallis test.

We found that the shoot length of lettuce in control, Ma-1 and Ma-10 was within a range of 2.9-3.1 mm after 4 days of testing. However, in Ma-100 and Scum treatments was between 2.2-2.5 mm, significantly different from the control (3.1 mm; $p < 0.05$; Figure 3a). After 7 days of incubation, the shoot length of lettuce in control was 4.7 mm, significantly longer than that in Ma and Scum treatments, ranging from 2.9-3.7 mm (Figure 3b). Shoot length of carrot was similar among the control (7.8 mm), Ma-1 (7.3 mm) and Scum-1 (7.1 mm) at the fourth day of the experiment (Fig. 3c). By the end of the experiment, the shoot length of carrot in all treatment varied between 7.5 and 9.3 mm, which was significantly different from that in control (11 mm; Figure 3d). Similar to the root development, a higher MC concentration of exposure resulted in a shorter shoot length of the carrot.

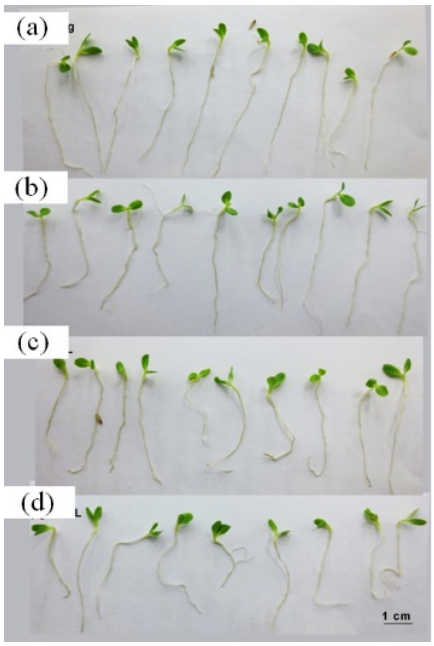


Figure 2. Shoot length of lettuce in control (a), Scum-1 (b), Scum-10 (c), and Scum-100 (d). Abbreviations as in Figure 1

Suan Sunandha Science and Technology Journal

The exhibition of shorter length of root and shoot of lettuce and carrot upon MC exposures compared to that in control over time (4 and 7 days) was in line with previous studies testing with rapeseed, rice, tomato (e.g. Chen et al., 2004; Ha & Pflugmacher, 2013; Pflugmacher et al., 2007; Wiegand et al., 2002). The cyanobacterial toxin MC are known to have negative effects on the activities of functional, biotransformation, and antioxidant enzymes in plants (Chen et al., 2004; MacKintosh et al., 1990; Pflugmacher, 2004; Stuven & Pflugmacher, 2007; Wiegand et al., 2002). Besides, MC could impact on the ATP-synthetase enzyme (Mikhailov, Harmala-Brasken, Hellman, Meriluoto, & Eriksson, 2003). Therefore, under exposure to MC, the lettuce and carrot would spend energy for both seedlings and dealing with the enzyme activity alteration. This would result in energy costs and diminish for normal development, consequently slowing down the root and shoot prolongation. Also, the MC exposed seedlings would suffer from the biochemical impacts as mentioned above consequently cell development impairment which needs further studies to clarify.

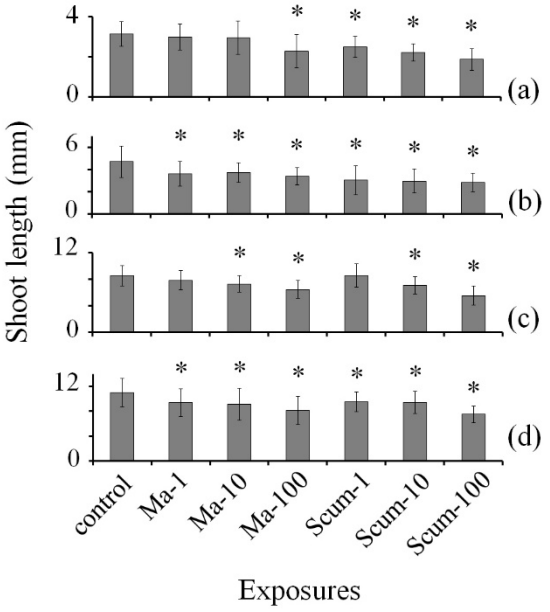


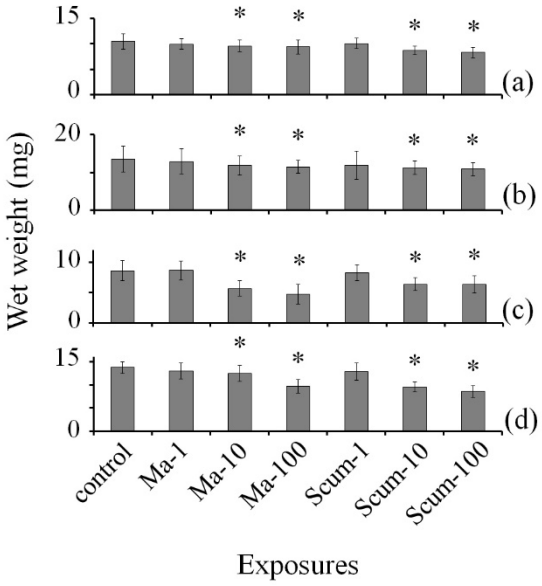
Figure 3. Shoot length of lettuce at 4 days (a) and 7 days (b), and of carrot at 4 days (c) and 7 days (d) of incubation. The asterisks indicated the significant difference ($p < 0.05$) between control and exposures by Kruskall-Wallis test. Abbreviations as in Figure 1.

In the case of shoot development, the impact of Ma-1 and Scum-1 was not shown after 4 days of incubation but clearly showed after 7 days of treatment. Maybe there was tolerance able of the shoot seedling to low MC concentration (1 µg/L) within a four-exposure day but impossible after a longer exposure time, 7 days. Also, the impacts on shoot and root length were already found at higher MC concentrations (10 and 100 µg/L) at the 4th day of experiment. Our result contributes to the understanding on the adverse effects of water containing MC on seedling of lettuce and carrot. *In situ* investigations (e.g. in farms from Dalat City, Vietnam) are suggested to clarify to impacts of the toxin on plant development and crop.

3.3 Wet weight of the lettuce and carrot upon treatments with MC-containing cyanobacterial extracts

At the 4th day of the experiment, the WW of lettuce seedlings in control, Ma-1 and Scum-1 was similar, and gained from 9.6-10.5 mg (Figure 4a). Similarly, at the 7th day of the experiment in control and the lowest MC concentration exposures (Ma-1 and Scum-1) was not significantly different, ranging from 11.9-13.5 mg (Figure 4b). However, the significant difference of lettuce seedling WW in control and other exposures (Ma-10, Ma-100, Scum-10, and Scum-100) was recorded after 4 and 7 days of the expriment ($p < 0.05$).

In the experiment with carrot, we found a similar trend with lettuce, no significant difference between WW in control (8.6 and 13.7 mg at 4th and 7th day, respectively) and lowest MC concentration incubation (Ma-1 and Scum-1) after 4 and 7 days of treatment (Figure 4c, d). We also recorded the significant difference of WW from control and higher MC exposures (Ma-10, Ma-100, Scum-10, and Scum-100) after 4 and 7 days of treatment.



Suan Sunandha Science and Technology Journal

Figure 4. The wet weight of lettuce at 4 days (a) and 7 days (b), and of carrot at 4 days (c) and 7 days (d) of incubation. The asterisks indicated the significant difference ($p < 0.05$) between control and exposures by Kruskall-Wallis test. Abbreviations as in Figure 1.

The WW reduction of lettuce and carrot in our study is supported by previous studies (Chen et al., 2004; Dao et al., 2014). As mentioned above, MC could diminish energy costs for plants and interfere with the enzyme activities in the cells of plants. The enzyme activity inhibition may lead to the decrease of water uptake into the cells. Also, the prevention of prolongation of root and shoot would consequence on the water volume reduction in the MC exposed seedlings. The influences would result in the reduction of water uptake and/or storage in cells and tissues of the plants, hence WW decreased. The similarly WW between Ma-1, Scum-1 and control revealed that the MC at the concentration of 1 µg/L was not strong enough to reduce the WW of the exposed seedlings. Furthermore, MC uptake and distribution in stems, rhizomes and leaves of aquatic macrophytes was reported (Pflugmacher, Wiegand, Beattie, Codd, & Steinberg, 1998). Other plants such as broccoli, mustard and duckweed are able to accumulate MC in their leaves and bark protein and whole plant after exposure (Jarvenpaa et al., 2007; Mitrovic et al., 2005). The uptake and accumulation of MC are not included in the current study and should be investigated with carrot and lettuce in future.

4. Conclusions

The seed germination of lettuce and carrot was negatively affected upon exposure to MC from both isolate and field samples of cyanobacteria. The effect of MC on seed germination of carrot was stronger than that of lettuce. The root and shoot development and prolongation were impaired by MC with concentration dependant. The WW of the seedlings was decreased under the MC treatment. The impacts of MC on germination and seedlings of plants in our study are believed to strongly link to the changes of enzyme activities and energy cost caused by MC during the cell processes at the early stage of the seedlings. We confirmed the toxic effects of MC from Vietnam waters at the environmental concentrations on common plants, lettuce and carrot. Bioaccumulation and distribution of MC in the plants are suggested to investigate in the future.

5. References

Al-Sultan, E. A., & Hatem, M. T. (2019). Toxic effects of purified microcystins from soil blue-green alga *Oscillatoria pseudogeminata* on tomato plant *Lycopersicon esculentum*. *Baghdad Science Journa*l, *16*(1), 169-177.

Chen, J., Song, L., Dai, J., Gan, N., & Liu, Z. (2004). Effect of microcystins on the growth and the activity of superoxide dismutase and peroxidase of rape (*Brassica napus* L.) and rice (*Oryza sativa* L.). *Toxicon*, *43*(4), 393-400.

Chorus, I., & Bartram, J. (1999). *Toxic cyanobacteria in water: A guide to their public health consequences, monitoring and management*. London: E & FN Spon.

Codd, G. A. (1999). Cyanobacterial toxins: their occurrence in aquatic environments and significance to health. *Bulletin de l'Institut Océanographique Monaco*, *19*, 483-500.

Dao, T. S., Cronberg, G., Nimptsch, J., Do-Hong, L. C., & Wiegand, C. (2010). Toxic cyanobacteria from Tri and Reservoir, Vietnam. *Nova Hedwigia*, *90*, 433-448.

Dao T. S., Le, T. H., Pham, T. L., Do-Hong, L. C., & Nguyen, P. D. (2014). Influences of cyanobacterial toxins microcystins on the seedling of plants. *Journal of Environmental Protection*, *5*, 35-41.

Duong, T. T., Le, T. P. Q., Dao, T. S., Pflugmacher, S., Rochelle-Newall, E., Hoang, T. K., ... Dang, D. K. (2013). Seasonal variation of cyanobacteria and microcystins in the Nui Coc Reservoir, Northern Vietnam. *Journal of Applied Phycology*, *25*, 1065-1075.

Ha, M. H., & Pflugmacher, S. (2013). Phytotoxic effects of the cyanobacterial neurotoxin anatoxin-a: Morphological, physiological and biochemical responses in aquatic macrophyte, *Ceratophyllum demersum*. *Toxicon*, *70*, 1-8.

Jarvenpaa, S., Lundberg-Niinisto, C., Spoof, L., Sjovall, O., Tyystjarvi, E., & Meriluoto, J. (2007). Effects of microcystins on broccoli and mustard, and analysis of accumulated toxin by

Suan Sunandha Science and Technology Journal

liquid chromatography-mass spectrometry. *Toxicon*, *49*(6), 865-874.

Kurki-Helasmo, K., & Meriluoto, J. (1998). Microcystin uptake inhibits growth and protein phosphatase activity in mustard (*Sinapis alba* L.) seedlings. *Toxicon*, *36*, 1921-1926.

MacKintosh, C., Beattie, K. A., Klumpp, S., Cohen, P., & Codd, G. A. (1990). Cyanobacterial microcystin-LR is a potent and specific inhibitor of protein phosphatases 1 and 2A from both mammals and higher plants. *FEBS Letters*, *264*(2), 187-192.

McElhiney, J., Lawton, L. A., & Leifert, C. (2001). Investigations into the inhibitory effects of microcystins on plant growth, and the toxicity of plant tissues following exposure. *Toxicon*, *39*(9), 1411-1420.

Mikhailov, A., Harmala-Brasken, A. S., Hellman, J., Meriluoto, J., & Eriksson, J. E. (2003). Identification of ATP-synthetase as a novel intracellular target for microcystin-LR. *Chemico-Biological Interactions*, *142*, 223-237.

Mitrovic, S. M., Allis, O., Furey, A., & James, K. J. (2005). Bioaccumulation and harmful effects of microcystin-LR in the aquatic plants *Lemna minor* and *Wolffia arrhiza* and the filamentous alga *Chladophora fracta*. *Ecotoxicology and Environmental Safety*, *61*(3), 345-352.

Nguyen, H. Q., Ha, N. T., & Pham, T. L. (2020). Inland harmful cyanobacterial bloom prediction in the eutrophic Tri An Reservoir using satellite band ratio and machine learning approaches. *Environmental Science and Pollution Research*, *27*, 9135-9151. doi:10.1007/s11356-019-07519-3

Paerl, H. W., & Huisman, J. (2009). Climate change: A catalyst for global expansion of harmful cyanobacterial blooms. *Environmental Microbiology Reports*, *1*(1), 27-37.

Pflugmacher, S. (2004). Promotion of oxidative stress in the aquatic macrophyte *Ceratophyllum demersum* during biotransformation of the cyanobacterial toxin microcystin-LR. *Aquatic Toxicology*, *70*(3), 169-178.

Pflugmacher, S., Aulhorn, M., & Grimm, M. (2007). Influence of a cyanobacterial crude extract containing microcystin-LR on the physiology and antioxidative defence systems of different spinach variants. *New Phytologist*, *175*(3), 482-489.

Pflugmacher, S., Wiegand, C., Beattie, K. A., Codd, G. A., & Steinberg, C. (1998). Uptake of the cyanobacterial hepatotoxin microcystin-LR by aquatic macrophytes. *Journal of Applied Botany*, *72*, 228-232.

Pham, T. L., Dao, T. S., Shimizu, K., Do-Hong, L. C., & Utsumi, M. (2015). Isolation and characterization of microcystin-producing cyanobacteria from Dau Tieng Reservoir, Vietnam. *Nova Hedwigia*, *101*, 3-20.

Pham, T. L., Dao, T. S., Tran, N. D., Nimptsch, J., Wiegand, C., & Motoo, U. (2017). Influence of environmental factors on cyanobacterial biomass and microcystin concentration in the Dau Tieng Reservoir, a tropical eutrophic water body in Vietnam. *International Journal of Limnology*, *53*, 89-100.

Pietsch, C., Wiegand, C., Ame, M. V., Nicklisch, A., Wunderlin, D., & Pflugmacher, S. (2001). The effects of a cyanobacterial crude extract on different aquatic organisms: Evidence for cyanobacterial toxin modulating factors. *Environmental Toxicology*, *16*(6), 535-542.

Stuven, J., & Pflugmacher, S. (2007). Antioxidative stress response of *Lepidium sativum* due to exposure to cyanobacterial secondary metabolites. *Toxicon*, *50*(1), 85-93.

Vasconcelos, V. M., & Pereira, E. (2001). Cyanobacteria diversity and toxicity in a wastewater treatment plant (Portugal). *Water Research*, *35*(5), 1354-1357.

Vo, T. M. C., Pham, T. L., & Dao, T. S. (2016). Detrimental impacts of toxic *Microcystis aeruginosa* from Vietnam on life hsitory traits of *Daphnia magna*. *Journal of Vietnamese Environment*, *8*(1), 56-61.

Weiss, J., Liebert, H. P., & Braune, W. (2000). Influence of microcystin-RR on growth and photosynthetic capacity of the duckweed *Lemna minor* L. *Journal of Applied Botany*, *74*, 100-105.

Suan Sunandha Science and Technology Journal

Wiegand, C., Peuthert, A., Pflugmacher, S., & Carmeli, S. (2002). Effects of microcin SF608 and microcystin-LR, two cyanobacterial compounds produced by *Microcystis* sp., on aquatic organisms. *Environmental Toxicology*, *17*(4), 400-406.

Zurawell, R. W., Chen, H., Burke, J. M., & Prepas, E. E. (2005). Hepatotoxic cyanobacteria: A review of the biological importance of microcystins in freshwater environments. *Journal of Toxicology and Environmental Health, Part B*, *8*, 1-37.

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Suan Sunandha Science and Technology Journal

Rough Interior Ideals and Rough Quasi-Ideals in Approximation Spaces of Semigroups under Preorder and Compatible Relations

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Abstract

In this paper, a rough interior ideal and a rough quasi-ideal in an approximation space of a semigroup under a preorder and compatible relation are proposed. As introduced above, corresponding examples are presented. Next, we provide a sufficient condition for the rough interior ideal (resp., rough quasi-ideal). Finally, we give a necessary and sufficient condition for a homomorphic image of the rough interior ideal (resp., rough quasi-ideal).

Keywords: Rough interior ideal, Rough quasi-ideal, Approximation space, Semigroup, Preorder and compatible relation

1. Introduction

In 1982, Pawlak introduced Pawlak's rough set theory. Mathematically, this is a classical tool for assessing problems and decision problems in many fields with respect to set theory. Pawlak's rough set theory has been regarded as an approximation processing model of sets induced by equivalence relations. Based on a Pawlak's approximation space induced by an equivalence relation **(**a pair of a non-empty universal set with an equivalence relation**)**, a non-empty subset of the given universe is approximated by the following sets (Pawlak, 1982).

The Pawlak's upper approximation set is the union of equivalent classes which have a non-empty intersection with the given non-empty subset **(**The set of all possibly elements with respect to a property of the given non-empty subset**).**

The Pawlak's lower approximation set is the union of equivalent classes which are subsets of the given non-empty subset **(**The set of all certainly elements with respect to a property of the given non-empty subset**).**

The Pawlak's boundary region is a difference of the upper approximation and the lower approximation **(**The set of all uncertain elements with respect to a property of the given non-empty subset**).**

The Pawlak's rough set of the given non-empty subset is defined by meaning of a pair of upper and lower approximations, where the difference of upper and lower approximations is a non-empty set**.** Otherwise, the given non-empty subset is said to be a Pawlak's definable set**.**

The combination of semigroup theory and Pawlak's rough set theory is one of the most interesting varieties. In 1997, Kuroki proposed the concepts of rough semigroups (resp. ideals) in approximation spaces of semigroups induced by congruence relations, and provided sufficient conditions of rough semigroups (resp. ideals) (Kuroki, 1997). In 2006, Xiao and Zhang introduced the concepts of rough completely prime ideals in approximation spaces of semigroups induced by congruence relations, and provided sufficient conditions of rough completely prime ideals (Xiao & Zhang, 2006). They verified the relationship between rough completely prime ideals (resp. ideals) and the homomorphic image of rough completely prime ideals (resp. ideals) under homomorphism problems. In 2012, Yaqoob, Aslam, and Chinram proposed the notions of rough prime bi-ideals in approximation spaces of semigroups induced by congruence relations, and provided sufficient conditions of rough prime bi-ideals (Yaqoob, Aslam, & Chinram, 2012).

Suan Sunandha Science and Technology Journal

Based on a binary relation between two universes, Prasertpong and Siripitukdet introduced a generalized rough set in 2019. Especially, they defined rough semigroups, rough ideals and rough completely prime ideals in semigroups under approximation spaces induced by preorder and compatible relations, including provided sufficient conditions for them, and proved necessary and sufficient conditions for their homomorphic images (Prasertpong & Siripitukdet, 2019).

In this research, after providing some fundamentals of semigroups, binary relations and generalized rough sets in Section 2, we firstly introduce rough interior ideals and rough quasi-ideals in semigroups under approximation spaces induced by preorder and compatible relations in Section 3. Then, we provide sufficient conditions for them. In the end, we give a necessary and sufficient condition for a homomorphic image of the rough interior ideal (resp., rough quasi-ideal).

2. Preliminaries

In this section, we recall important terms which will be used in a subsequent section.

2.1 Some basic attributes in semigroups

Definition 2.1.1 A *semigroup* $(S,\cdot)$ is defined as an algebraic system, where S is a non-empty set and " $\cdot$ " is an associative binary operation on S. Throughout this paper, S stands for a semigroup (Clifford & Preston, 1961).

Definition 2.1.2 An element s in S is called an *idempotent element* if $s^2 = s$. For any $X \subseteq S$, the set of all idempotents in X is denoted by $E(X)$ (Clifford & Preston, 1961).

Definition 2.1.3 Let X be a non-empty subset of S. X is called a *right ideal* (resp., a *left ideal*) of S if $XS \subseteq X$ (resp., $SX \subseteq X$). X is called an *ideal* of S if it is a right ideal and a left ideal of S (Clifford & Preston, 1961).

Definition 2.1.4 S is called a *semisimple semigroup* if $X = E(X)$ for every ideal X of S (Clifford & Preston, 1961).

Definition 2.1.5 S is called a *commutative semigroup* if $s_1 s_2 = s_2 s_1$ for all $s_1, s_2 \in S$ (Howie, 1976).

Definition 2.1.6 A non-empty subset X of S is called an *interior ideal* of S if $SXS \subseteq X$ (Mordeson, Malik, & Kuroki, 2010).

Theorem 2.1.7 S is a semisimple semigroup if and only if

$$X \cap Y = XY$$

for every interior ideal X and every ideal Y of S (Mordeson, Malik, & Kuroki, 2010).

Definition 2.1.8 A non-empty subset X of S is called a *quasi-ideal* of S if $XS \cap SX \subseteq X$ (Mordeson, Malik, & Kuroki, 2010).

2.2 Some basic definitions of relations

Throughout this paper, U and V denote two non-empty universal sets.

Definition 2.2.1 (Zach, 2017) Let $P(U \times V)$ be a collection of all subsets of $U \times V$. An element in $P(U \times V)$ is called a *binary relation from U to V*. An element in $P(U \times V)$ is called a *binary relation on* U if $U = V$.

Definition 2.2.2 (Zach, 2017)

(1) θ is called *reflexive* if $(u,u) \in \theta$ for all $u \in U$.

(2) θ is called *transitive* if for each $u_1, u_2, u_3 \in U$, $(u_1,u_2) \in \theta$ and $(u_2, u_3) \in \theta$ imply $(u_1,u_3) \in \theta$.

(3) θ is called *symmetric* if for each $u_1, u_2 \in U$, $(u_1,u_2) \in \theta$ implies $(u_2,u_1) \in \theta$.

(4) If θ is reflexive and transitive, then θ is called a *preorder relation*.

(5) If θ is reflexive, transitive and symmetric, then θ is called an *equivalence relation*.

Definition 2.2.3 Let θ be an equivalence relation on U. For an element $u \in U$, the set (Zach, 2017)

$$[u]_\theta := \{v \in V : (u,v) \in \theta\} \qquad (2.2.1)$$

is called an *equivalence class of u induced by* θ.

Definition 2.2.4 Let θ be a binary relation on S. θ is called *compatible (with the operation on S)* if for each $s_1, s_2, s_3 \in S$, $(s_1,s_2) \in \theta$ implies $(s_1s_3, s_2s_3) \in \theta$ and $(s_3s_1, s_3s_2) \in \theta$. If θ is an equivalence relation with compatible, then it is called a congruence (Howie, 1976).

2.3 Fundamentals of generalized rough sets in semigroups

Definition 2.3.1 Let θ be a binary relation from U to V. For an element $u \in U$, the set

$$S_\theta(u) := \{v \in V : (u,v) \in \theta\} \qquad (2.3.1)$$

is called a *successor class of u induced by* θ

Suan Sunandha Science and Technology Journal

(Prasertpong & Siripitukdet, 2019).

Definition 2.3.2 Let θ be a binary relation from U to V. For an element $u_1 \in U$, the set in Equation (2.3.2) as

$PS_\theta(u_1) := \{u_2 \in U : S_\theta(u_2) \subseteq S_\theta(u_1)\}$

is called a *portion of the successor class of* u_1 *induced by* θ. $\mathcal{PS}_\theta(U)$ is denoted as a collection of $PS_\theta(u)$ for all $u \in U$ (Prasertpong & Siripitukdet, 2019).

Definition 2.3.3 Let θ be a binary relation from U to V. The triple $(U, V, \mathcal{PS}_\theta(U))$ is called a $\mathcal{PS}_\theta(U)$-*approximation space*. If we change V to U, then $(U, V, \mathcal{PS}_\theta(U))$ is replaced by a pair $(U, \mathcal{PS}_\theta(U))$ (Prasertpong & Siripitukdet, 2019).

Definition 2.3.4 Let $(U, V, \mathcal{PS}_\theta(U))$ be a $\mathcal{PS}_\theta(U)$-approximation space and let X be a non-empty subset of U. The set in Equation (2.3.3) as

$$\overline{\theta}(X) := \{u \in U : PS_\theta(u) \cap X \neq \emptyset\}$$

is called a $\mathcal{PS}_\theta(U)$-*upper approximation of* X (The set of all possibly elements with respect to a property of the given non-empty subset). The set in Equation (2.3.4) as

$$\underline{\theta}(X) := \{u \in U : PS_\theta(u) \subseteq X\}$$

is called a $\mathcal{PS}_\theta(U)$-*lower approximation of* X (The set of all certainly elements with respect to a property of the given non-empty subset). The set in Equation (2.3.5) as

$$\theta_{bnd}(X) := \overline{\theta}(X) - \underline{\theta}(X)$$

is called a $\mathcal{PS}_\theta(U)$-*boundary region of* X (The set of all uncertain elements with respect to a property of the given non-empty subset). If $\theta_{bnd}(X) \neq \emptyset$, then $\theta(X) := (\overline{\theta}(X), \underline{\theta}(X))$ is called a $\mathcal{PS}_\theta(U)$-*rough set of* X. In this way, we say that X is a $\mathcal{PS}_\theta(U)$-*rough set*. If $\theta_{bnd}(X) = \emptyset$, then X is called a $\mathcal{PS}_\theta(U)$-*definable set* (Prasertpong & Siripitukdet, 2019).

Remark 2.3.5 Based on Definition 2.3.4, note that every Pawlak's rough set is a $\mathcal{PS}_\theta(U)$-rough set. Conversely, it is not true in general. Indeed, a $\mathcal{PS}_\theta(U)$-rough set is a generalization of a Pawlak's rough set whenever a binary relation is an equivalence relation, that is, Equation (2.2.1) and Equation (2.3.2) are identical. As proposed above, a corresponding example is considered as Example 1 in Prasertpong and Siripitukdet (2019).

Proposition2.3.6 Let $(U, V, \mathcal{PS}_\theta(U))$ be a $\mathcal{PS}_\theta(U)$-approximation space. If X and Y are non-empty subsets of U, then the following statements hold.

(1) $\overline{\theta}(U) = U$ and $\underline{\theta}(U) = U$.
(2) $X \subseteq \overline{\theta}(X)$ and $\underline{\theta}(X) \subseteq X$.
(3) $\underline{\theta}(X \cap Y) = \underline{\theta}(X) \cap \underline{\theta}(Y)$.
(4) If $X \subseteq Y$, then $\overline{\theta}(X) \subseteq \overline{\theta}(Y)$ and $\underline{\theta}(X) \subseteq \underline{\theta}(Y)$ (Prasertpong & Siripitukdet, 2019).

Definition 2.3.7 Let $(U, V, \mathcal{PS}_\theta(U))$ be a $\mathcal{PS}_\theta(U)$-approximation space and let X be a non-empty subset of U. If $\underline{\theta}(U)$ is a non-empty proper subset of X, then X is called a *set over a non-empty interior set* (Prasertpong & Siripitukdet, 2019).

Remark 2.3.8 Using the similar method in the proof of Proposition 4 in Prasertpong and Siripitukdet (2019), it is easy to see that if X is a non-empty subset of U over a non-empty interior set, then it is a $\mathcal{PS}_\theta(U)$-rough set.

Definition 2.3.9 Let $(S, \mathcal{PS}_\theta(S))$ be a $\mathcal{PS}_\theta(S)$-approximation space. $(S, \mathcal{PS}_\theta(S))$ is called a $\mathcal{PS}_\theta(S)$-*approximation space type* PCR if θ is a preorder and compatible relation (Prasertpong & Siripitukdet, 2019).

Definition 2.3.10 Let $(S, \mathcal{PS}_\theta(S))$ be a $\mathcal{PS}_\theta(S)$-approximation space type PCR. θ is called a *complete relation* if

$$(PS_\theta(s_1))(PS_\theta(s_2)) = PS_\theta(s_1 s_2)$$

for all $s_1, s_2 \in S$. $(S, \mathcal{PS}_\theta(S))$ is called a $\mathcal{PS}_\theta(S)$-*approximation space type* CR if θ is a complete relation (Prasertpong & Siripitukdet, 2019).

Remark 2.3.11 According to Definitions 2.3.9 and 2.3.10, every $\mathcal{PS}_\theta(S)$-approximation space type CR is a $\mathcal{PS}_\theta(S)$-approximation space type PCR.

Proposition 2.3.12 Let $(S, \mathcal{PS}_\theta(S))$ be a $\mathcal{PS}_\theta(S)$-approximation space. Then the following statements hold.

(1) If $(S, \mathcal{PS}_\theta(S))$ is a $\mathcal{PS}_\theta(S)$-approximation space type PCR, then $(\overline{\theta}(X))(\overline{\theta}(Y)) \subseteq \overline{\theta}(XY)$ for every non-empty subsets X and Y of S.

(2) If $(S, \mathcal{PS}_\theta(S))$ is a $\mathcal{PS}_\theta(S)$-approximation space type CR, then $(\underline{\theta}(X))(\underline{\theta}(Y)) \subseteq \underline{\theta}(XY)$ for every non-empty subsets X and Y of S (Prasertpong & Siripitukdet, 2019).

Theorem 2.3.13 Let $(S, \mathcal{PS}_\theta(S))$ be a $\mathcal{PS}_\theta(S)$-approximation space and let X be a non-empty subset of S. If X is an ideal of S in $(S, \mathcal{PS}_\theta(S))$ type PCR, then $\overline{\theta}(X)$ is an ideal of S (Prasertpong & Siripitukdet, 2019).

Suan Sunandha Science and Technology Journal

Proposition 2.3.14 Let f be an epimorphism from S in $(S, \mathcal{PS}_\theta(S))$ to T in $\left(T, \mathcal{PS}_\vartheta(T)\right)$, where the binary relation θ is defined by Equation (2.3.6) as

$\theta = \{(s_1, s_2) \in S \times S : (f(s_1), f(s_2)) \in \vartheta\}$.

Then the following statements hold.

(1) $f(\overline{\theta}(X)) = \overline{\vartheta}(f(X))$ for every non-empty subset X of S.

(2) If f is injective, then $f(\underline{\theta}(X)) = \underline{\vartheta}(f(X))$ for every non-empty subset X of S (Prasertpong & Siripitukdet, 2019).

3. Main Results

In this section, we introduce a rough interior ideal and a rough quasi-ideal in a $\mathcal{PS}_\theta(S)$-approximation space type PCR. Then we provide sufficient conditions for them. Based on homomorphism problem in semigroup, we give a necessary and sufficient condition for a homomorphic image of the rough interior ideal (resp., rough quasi-ideal).

Definition 3.1 Let $\left(S, \mathcal{PS}_\theta(S)\right)$ be a $\mathcal{PS}_\theta(S)$-approximation space type PCR and let X be a non-empty subset of S. X is called a $\mathcal{PS}_\theta(S)$-*upper rough interior ideal* if $\overline{\theta}(X)$ is an interior ideal of S. X is called a $\mathcal{PS}_\theta(S)$-*lower rough interior ideal* if $\underline{\theta}(X)$ is an interior ideal of S. X is called a $\mathcal{PS}_\theta(S)$-*rough interior ideal* if it is a $\mathcal{PS}_\theta(S)$-upper rough interior ideal, a $\mathcal{PS}_\theta(S)$-lower rough interior ideal and a $\mathcal{PS}_\theta(S)$-rough set. Similarly, we can define a $\mathcal{PS}_\theta(S)$-rough quasi-ideal.

We consider the following example.

Example 3.2 Based on Example 3 in Prasertpong and Siripitukdet (2019), we let $S = \{s_1, s_2, s_3, s_4, s_5\}$ be a semigroup with multiplication rules defined by the following table.

Table 1. The multiplication table on S.

	s_1	s_2	s_3	s_4	s_5
s_1	s_1	s_1	s_3	s_1	s_5
s_2	s_1	s_2	s_3	s_1	s_5
s_3	s_3	s_3	s_3	s_3	s_3
s_4	s_1	s_1	s_3	s_4	s_5
s_5	s_5	s_5	s_3	s_5	s_5

Let θ be a relation defined as follows:
$\{(s_1, s_1), (s_1, s_2), (s_1, s_4), (s_2, s_1), (s_2, s_2), (s_2, s_4), (s_3, s_3), (s_3, s_5), (s_4, s_1), (s_4, s_2), (s_4, s_4), (s_5, s_5)\}$.
Then, it is easily seen that θ is a preorder and compatible relation. According to Equation (2.3.1) in Definition 2.3.1, it follows that

$S_\theta(s_1) = \{s_1, s_2, s_4\}$,
$S_\theta(s_2) = \{s_1, s_2, s_4\}$,
$S_\theta(s_3) = \{s_3, s_5\}$,
$S_\theta(s_4) = \{s_1, s_2, s_4\}$,
$S_\theta(s_5) = \{s_5\}$.

According to Equation (2.3.2) in Definition 2.3.2, it follows that

$PS_\theta(s_1) = S_\theta(s_1)$,
$PS_\theta(s_2) = S_\theta(s_2)$,
$PS_\theta(s_3) = S_\theta(s_3)$,
$PS_\theta(s_4) = S_\theta(s_4)$,
$PS_\theta(s_5) = S_\theta(s_5)$.

Suppose that $X = \{s_2, s_3, s_5\}$ is a non-empty subset of S, which is a set for an approximation in $\left(S, \mathcal{PS}_\theta(S)\right)$ type PCR. Then, by Equations (2.3.3) and (2.3.4) in Definition 2.3.4, we see that $\overline{\theta}(X) = S$ and $\underline{\theta}(X) = \{s_3, s_5\}$, respectively. Hence $\theta_{bnd}(X) \neq \emptyset$, and so X is a $\mathcal{PS}_{\underline{\theta}}(S)$-rough set. Moreover, it is easily verified that $\overline{\theta}(X)$ and $\underline{\theta}(X)$ are interior ideals and quasi-ideals. Moreover, we observe that X is a $\mathcal{PS}_\theta(S)$-(resp., upper, lower) rough interior ideal and X is a $\mathcal{PS}_\theta(S)$-(resp., upper, lower) rough quasi-ideal.

We now come to main results.

Theorem 3.3 Let $\left(S, \mathcal{PS}_\theta(S)\right)$ be a $\mathcal{PS}_\theta(S)$-approximation space and let X be a non-empty subset of S. Then we have the following statements.

(1) If X is an interior ideal of S in $\left(S, \mathcal{PS}_\theta(S)\right)$ type PCR, then it is a $\mathcal{PS}_\theta(S)$-upper rough interior ideal.

(2) If X is an interior ideal of S in $\left(S, \mathcal{PS}_\theta(S)\right)$ type CR with respect to a non-empty $\underline{\theta}(X)$, then it is a $\mathcal{PS}_\theta(S)$-lower rough interior ideal.

(3) If X is an interior ideal of S over a non-empty interior set in $\left(S, \mathcal{PS}_\theta(S)\right)$ type CR, then it is a $\mathcal{PS}_\theta(S)$-rough interior ideal.

Proof. (1) Suppose that X is an interior ideal of S in $\left(S, \mathcal{PS}_\theta(S)\right)$ type PCR. Then $SXS \subseteq X$. By Proposition 2.3.6 (2), we get $X \subseteq \overline{\theta}(X)$. Thus $\overline{\theta}(X) \neq \emptyset$. By Proposition 2.3.6 (4), we obtain $\overline{\theta}(SXS) \subseteq \overline{\theta}(X)$. By Proposition 2.3.6 (1), we have $\overline{\theta}(S) = S$. From Proposition 2.3.12 (1), it follows that

$S\left(\overline{\theta}(X)\right)S = \left(\overline{\theta}(S)\right)\left(\overline{\theta}(X)\right)\left(\overline{\theta}(S)\right)$
$\subseteq \overline{\theta}(SXS) \subseteq \overline{\theta}(X)$.

Hence $\overline{\theta}(X)$ is an interior ideal of S. Therefore, X is a $\mathcal{PS}_\theta(S)$-upper rough interior ideal.

(2) From Propositions 2.3.6 (1) and (4), 2.3.12 (2) and using the similar method in the proof of argument (1), we can prove that the statement is true under $\left(S, \mathcal{PS}_\theta(S)\right)$ type CR.

(3) From Remark 2.3.8 and arguments (1) and

Suan Sunandha Science and Technology Journal

(2), we can prove that the statement is true.

Theorem 3.4 Let $\left(S,\mathcal{PS}_\theta(S)\right)$ be a $\mathcal{PS}_\theta(S)$-approximation space and let X be a non-empty subset of S. Then we have the following statements.

(1) If X is a quasi-ideal of S in $\left(S,\mathcal{PS}_\theta(S)\right)$ type PCR, where S is semisimple and commutative, then it is a $\mathcal{PS}_\theta(S)$-upper rough quasi-ideal.

(2) If X is a quasi-ideal of S in $\left(S,\mathcal{PS}_\theta(S)\right)$ type CR with respect to a non-empty $\underline{\theta}(X)$, then it is a $\mathcal{PS}_\theta(S)$-lower rough quasi-ideal.

(3) If X is a quasi-ideal of S over a non-empty interior set in $\left(S,\mathcal{PS}_\theta(S)\right)$ type CR, where S is semisimple and commutative, then it is a $\mathcal{PS}_\theta(S)$-rough quasi-ideal.

Proof. (1) Suppose that X is a quasi-ideal of S in $\left(S,\mathcal{PS}_\theta(S)\right)$ type PCR, where S is semisimple and commutative. Then $XS\cap SX\subseteq X$. By Proposition 2.3.6 (4), we get that $\overline{\theta}(XS\cap SX)\subseteq\overline{\theta}(X)$. Note that XS is a right ideal and SX is a left ideal of S. Since S is commutative, XS and SX are ideals of S. Then, by Theorem 2.3.13, we obtain that $\overline{\theta}(XS)$ and $\overline{\theta}(SX)$ are ideals of S. Note that XS is an interior ideal of S. Then, by Theorem 3.3 (1), we obtain $\overline{\theta}(XS)$ is an interior ideal of S. Since S is semisimple, by Theorem 2.1.7, we get that

$$XS\cap SX=(XS)(SX)$$

and

$$\overline{\theta}(XS)\cap\overline{\theta}(SX)=\left(\overline{\theta}(XS)\right)\left(\overline{\theta}(SX)\right).$$

From Propositions 2.3.6 (1) and 2.3.12 (1), it follows that

$$\begin{aligned}&\left(\overline{\theta}(X)\right)S\cap S\left(\overline{\theta}(X)\right)\\&=\left(\overline{\theta}(X)\right)\left(\overline{\theta}(S)\right)\cap\left(\overline{\theta}(S)\right)\left(\overline{\theta}(X)\right)\\&\subseteq\overline{\theta}(XS)\cap\overline{\theta}(SX)\\&=\left(\overline{\theta}(XS)\right)\left(\overline{\theta}(SX)\right)\\&\subseteq\overline{\theta}\left((XS)(SX)\right)\\&=\overline{\theta}\left((XS)\cap(SX)\right)\\&\subseteq\overline{\theta}(X).\end{aligned}$$

Thus $\overline{\theta}(X)$ is a quasi-ideal of S. This means that X is a $\mathcal{PS}_\theta(S)$-upper rough quasi-ideal.

(2) Suppose that X is a quasi-ideal of S in $\left(S,\mathcal{PS}_\theta(S)\right)$ type CR with respect to a non-empty $\underline{\theta}(X)$. Then $XS\cap SX\subseteq X$. From Proposition 2.3.6 (1), (3) and (4) and Proposition 2.3.12 (2), it follows that

$$\begin{aligned}&\left(\underline{\theta}(X)\right)S\cap S\left(\underline{\theta}(X)\right)\\&=\left(\underline{\theta}(X)\right)\left(\underline{\theta}(S)\right)\cap\left(\underline{\theta}(S)\right)\left(\underline{\theta}(X)\right)\\&\subseteq\underline{\theta}(XS)\cap\underline{\theta}(SX)\\&=\underline{\theta}\left((XS)\cap(SX)\right)\\&\subseteq\underline{\theta}(X).\end{aligned}$$

Hence $\underline{\theta}(X)$ is a quasi-ideal of S. It follows that X is a $\mathcal{PS}_\theta(S)$-lower rough quasi-ideal.

(3) From Remark 2.3.8 and arguments (1) and (2), we can prove that the statement is true.

Theorem 3.5 Let f be an epimorphism from S in $\left(S,\mathcal{PS}_\theta(S)\right)$ to T in $\left(T,\mathcal{PS}_\vartheta(T)\right)$ type PCR, where θ is defined as Equation (2.3.6) in Proposition 2.3.14. If X is a non-empty subset of S and f is injective, then we have the following statements.

(1) $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-upper rough interior ideal if and only if X is a $\mathcal{PS}_\theta(S)$-upper rough interior ideal.

(2) $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-lower rough interior ideal if and only if X is a $\mathcal{PS}_\theta(S)$-lower rough interior ideal.

(3) $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-rough interior ideal if and only if X is a $\mathcal{PS}_\theta(S)$-rough interior ideal.

Proof. (1) Suppose that $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-upper rough interior ideal. Then, we have that

$$T\left(\overline{\vartheta}\left(f(X)\right)\right)T\subseteq\overline{\vartheta}\left(f(X)\right).$$

Let $s_1\in S\left(\overline{\theta}(X)\right)S$. By Proposition 2.3.14 (1), we obtain

$$\begin{aligned}f(s_1)&\in f\left(S\left(\overline{\theta}(X)\right)S\right)=T\left(\overline{\vartheta}\left(f(X)\right)\right)T\\&\subseteq\overline{\vartheta}\left(f(X)\right)=f\left(\overline{\theta}(X)\right).\end{aligned}$$

Thus, there exists $s_2\in\overline{\theta}(X)$ such that $f(s_1)=f(s_2)$. Hence $PS_\theta(s_2)\cap X\neq\emptyset$. Since f is injective, we have $s_1=s_2$. Thus $PS_\theta(s_1)\cap X\neq\emptyset$. Hence $s_1\in\overline{\theta}(X)$. Whence $S\left(\overline{\theta}(X)\right)S\subseteq\overline{\theta}(X)$. Hence $\overline{\theta}(X)$ is an interior ideal of S. Therefore, X is a $\mathcal{PS}_\theta(S)$-upper rough interior ideal.

Conversely, assume that X is a $\mathcal{PS}_\theta(S)$-upper rough interior ideal. Then $S\left(\overline{\theta}(X)\right)S\subseteq\overline{\theta}(X)$. Thus $f\left(S\left(\overline{\theta}(X)\right)S\right)\subseteq f\left(\overline{\theta}(X)\right)$. By Proposition 2.3.14 (1), we see that

$$\begin{aligned}T\left(\overline{\vartheta}\left(f(X)\right)\right)T&=f\left(S\left(\overline{\theta}(X)\right)S\right)\\&\subseteq f\left(\overline{\theta}(X)\right)=\overline{\vartheta}\left(f(X)\right).\end{aligned}$$

Hence $\overline{\vartheta}\left(f(X)\right)$ is an interior ideal of T. Therefore $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-upper rough interior ideal.

(2) By Proposition 2.3.14 (2) and using the similar method in the proof of argument (1), we can prove that the statement is true.

(3) Under the injective mapping f, the proof is obvious from arguments (1) and (2).

Theorem 3.6 Let f be an epimorphism from S in $\left(S,\mathcal{PS}_\theta(S)\right)$ to T in $\left(T,\mathcal{PS}_\vartheta(T)\right)$ type PCR, where θ is defined as Equation (2.3.6) in Proposition 2.3.14. If X is a non-empty subset of S and f is injective, then we have the following statements.

(1) $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-upper rough quasi-ideal if and only if X is a $\mathcal{PS}_\theta(S)$-upper rough quasi-ideal.

(2) $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-lower rough quasi-ideal if and only if X is a $\mathcal{PS}_\theta(S)$-lower rough quasi-ideal.

(3) $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-rough quasi-ideal if and only if X is a $\mathcal{PS}_\theta(S)$-rough quasi-ideal.

Proof. (1) Suppose that $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-upper rough quasi-ideal. Then $\overline{\vartheta}\left(f(X)\right)$ is a quasi-ideal of T. Thus $\left(\overline{\vartheta}\left(f(X)\right)\right)T\cap T\left(\overline{\vartheta}\left(f(X)\right)\right)\subseteq\overline{\vartheta}\left(f(X)\right)$. Let $s_1\in\left(\overline{\theta}(X)\right)S\cap S\left(\overline{\theta}(X)\right)$. Then, we have that $s_1\in\left(\overline{\theta}(X)\right)S$ and $s_1\in S\left(\overline{\theta}(X)\right)$. Hence $f(s_1)\in f\left(\left(\overline{\theta}(X)\right)S\right)$ and $f(s_1)\in f\left(S\left(\overline{\theta}(X)\right)\right)$. By

Suan Sunandha Science and Technology Journal

Proposition 2.3.14 (1), we get that $f(s_1) \in \left(\overline{\vartheta}(f(X))\right)T \cap T\left(\overline{\vartheta}(f(X))\right)$. We observe that

$$f(s_1) \in \left(\overline{\vartheta}(f(X))\right)T \cap T\left(\overline{\vartheta}(f(X))\right) \subseteq \overline{\vartheta}(f(X)) = f\left(\overline{\theta}(X)\right).$$

Thus, there exists $s_2 \in \overline{\theta}(X)$ such that $f(s_1) = f(s_2)$. Hence $PS_\theta(s_2) \cap X \neq \emptyset$. Since f is injective, we have $s_1 = s_2$. Thus $PS_\theta(s_1) \cap X \neq \emptyset$. Hence $s_1 \in \overline{\theta}(X)$. Whence $\left(\overline{\theta}(X)\right)S \cap S\left(\overline{\theta}(X)\right) \subseteq \overline{\theta}(X)$, which yields $\overline{\theta}(X)$ is a quasi-ideal of S. It follows that X is a $\mathcal{PS}_\theta(S)$-upper rough quasi-ideal.

Conversely, suppose X is a $\mathcal{PS}_\theta(S)$-upper rough quasi-ideal. Then $\overline{\theta}(X)$ is a quasi-ideal of S. Thus

$$\left(\overline{\theta}(X)\right)S \cap S\left(\overline{\theta}(X)\right) \subseteq \overline{\theta}(X).$$

Hence

$$f\left(\left(\overline{\theta}(X)\right)S \cap S\left(\overline{\theta}(X)\right)\right) \subseteq f\left(\overline{\theta}(X)\right).$$

Since f is injective, it is easy to prove that

$$f\left(\left(\overline{\theta}(X)\right)S\right) \cap f\left(S\left(\overline{\theta}(X)\right)\right) = f\left(\left(\overline{\theta}(X)\right)S \cap S\left(\overline{\theta}(X)\right)\right).$$

By Proposition 2.3.14 (1), we obtain that

$$\left(\overline{\vartheta}(f(X))\right)T \cap T\left(\overline{\vartheta}(f(X))\right) = f\left(\left(\overline{\theta}(X)\right)S\right) \cap f\left(S\left(\overline{\theta}(X)\right)\right) \subseteq f\left(\overline{\theta}(X)\right) = \overline{\vartheta}(f(X)).$$

Thus $\overline{\vartheta}(f(X))$ is a quasi-ideal of T. Consequently $f(X)$ is a $\mathcal{PS}_\vartheta(T)$-upper rough quasi-ideal.

(2) By Proposition 2.3.14 (2) and using the similar method in the proof of argument (1), we can prove that the statement is true.

(3) Under the injective mapping f, the proof is obvious from arguments (1) and (2).

4. Conclusions and Suggestions

Based on the generalized rough set model in Prasertpong and Siripitukdet **(**2019**)**, we introduced a rough interior ideal and a rough quasi-ideal in a semigroup under an approximation space induced by a preorder and compatible relation and derived sufficient conditions for them**.** Also, we proved a relationships between the interior ideal **(**resp**.** quasi-ideal**)** and its homomorphic image**.** Observe that we obtained results in semigroups by using a non-symmetric relation, which differ from Kuroki, **(**1997**)**, Xiao and Zhang **(**2006**)** and Yaqoob et al. (2012**).** Then, the novel rough set in Prasertpong and Siripitukdet **(**2019**)** can be used in a semigroup for approximation processings in terms of crisp sets as Section 3**.** In the end, we hope that main results in this work may provide a powerful tool for assessment and decision problems in various fields with respect to information sciences and computer sciences**.**

5. References

Clifford, A. H., & Preston, G. B. (1961). *The algebraic theory of semigroups I, II*. American Mathematical Society.

Howie, J. M., (1976). *An introduction to semigroup theory*. London: Academic Press.

Kuroki, N. (1997). Rough ideals in semigroups. *Information Sciences*, *100*, 139-163.

Mordeson, J. N., Malik, D. S., & Kuroki, N. (2010). *Fuzzy semigroups*. Germany: Springer-Verlag Berlin, Heidelberg.

Pawlak, Z. (1982). Rough sets. *International Journal of Computer and Information Science*, *11*(5), 341-356.

Prasertpong, R., & Siripitukdet, M. (2019). Applying generalized rough set concepts to approximation spaces of semigroups. *IAENG International Journal of Applied Mathematics*, *49*(1), 51-60.

Xiao, Q. M., & Zhang, Z. L. (2006). Rough prime ideals and rough fuzzy prime ideals in semigroups. *Information Sciences*, *176*(6), 725-733.

Yaqoob, N., Aslam, M., & Chinram, R. (2012). Rough prime bi-ideals and rough fuzzy prime bi-ideals in semigroups. *Annals of Fuzzy Mathematics and Informatics*, *3*(2), 203-211.

Zach, R. (2017). *Sets, logic and computation*. University of Calgary.

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Modification of Leaf Blower-vac (Grizzly ELS 2500/8) for Sampling Arthropods in Watermelon (*Citrullus lanatus* Thunb.) Field

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Abstract

Grizzly ELS 2500/8 blower-vac was remodeled for arthropod suction sampling and possibly as a non-chemical pest management tool using readily available materials. With an installed intake nozzle (area 0.0020 m^2), the modified sampler was used in conjunction with a sampling enclosure (area 0.0707 m^2) for sampling arthropods associated with watermelon across 20 samples with 6 sub-samples each using 120 and 20 seconds sampling duration, respectively. Results indicated that overall, 427 individuals were collected across 10 arthropod orders and that about ¾ of the samples were extracted within the 1st sub-sampling duration. Overall, the efficiency and effectiveness of the modified machine were attributed to its lightweight, smaller intake nozzle diameter, high proportion of arthropods extracted vis-à-vis sampling duration, and easier constructability vis-à-vis previously reported ones. Additionally, cost implication was cheaper than the cost of many conventional suction samplers, particularly, the popular Dietrick vacuum (D-vac). Hence, it is recommended for use as a suitable alternative, particularly, by researchers and farmers in developing countries who may not be able to afford other more expensive suction machines.

Keywords: Suction enclosure, Suction duration, Suction sampling

1. Introduction

Aside its importance health wise, Watermelon, *Citrullus lanatus* Thunb. (Cucurbitaceae), is an economically and nutritionally important fruit cultivated in most regions of the world (Okrikata, Ogunwolu, & Odiaka, 2020). The diversity of arthropod species on the crop have been reported to be high (Lima et al., 2014) and occupying different feeding guilds such as phytophagous (defoliators, sap suckers, flower feeders and fruit feeders), pollinators, predators and parasitoids (Okrikata & Ogunwolu, 2019; Okrikata, Ogunwolu, & Ukwela, 2019).

Arthropod surveillance and measurement of their abundance is an integral part of integrated pest management (IPM) (Cherrill, 2015; Thomas, 2012). For these to be achieved, the choice and/or use of arthropod sampling technique(s) is very important. There are a variety of arthropod sampling techniques each with their weaknesses and strengths (Zou et al., 2016). For instance, pitfall traps (for sampling ground dwelling arthropods) provides an estimate of "activity density" while sweep nets (for sampling fast flying insects) provides relative estimates of insect abundance. However, unlike the aforementioned which provides relative estimates of abundance, suction samplers have the advantage of a more complete extraction of both tiny and larger invertebrate species (e.g., some beetle species) and immature forms (e.g., caterpillars) from plant parts, and if used in combination with an enclosure (covering a specified area of the field); they have been shown to give estimates of "actual density" (Grootaert, Pollet, Dekoninck & van Achterberg, 2010; Okrikata et al., 2019). Though not most suitable for fast flying and noise/disturbance sensitive insects like some Odonotans and hymenopterans, their use in conjunction with sampling enclosures have been shown to largely overcome this limitation (Zou et al., 2016).

For the purpose of suction sampling, Dietrick vacuum (D-vac) was the first to be invented around the 1960s (Bell, Wheater, Henderson, & Cullen, 2002). Despite being more effective than the sweeping and beating sampling methods (Hand, 1986); it is reported to have low

Suan Sunandha Science and Technology Journal

suction speed when compared with modern suction machines. Furthermore, the machine is largely bulky, noisy and costlier (Cherrill, 2015; Stewart & Wright, 1995). To deal with these shortcomings, some suction samplers (generally called, the 2nd generation suction samplers) were invented and these were based on "reverse leaf blower design" (Buffington & Redak, 1998; Harper & Guyunn, 1998; Thomas, 2012). Due to their effectiveness in picking arthropods, some have proposed their being used in pest control (Boiteau, Misener, Singh, & Bernard, 1992). However, since the designs of the suction machines are different, it is not surprising that their efficiency and application have been reported to be different also (Reed, Adams, & Abel, 2010).

Conversion of garden "blow and vac" machines for more efficient, lighter-weight and cheaper suction sampling for use particularly, by researchers and farmers in low income countries has been an area of interest for some or perhaps few scientists and technicians (Stewart & Wright, 1995; Zou et al., 2016). The efficiency of any sampling technique critically depends on sampling duration and as such, the efficiency of suction samplers are mainly determined by estimating the time it takes for it to extract an acceptable proportion (for instance 75%) of the target arthropod(s). This can be done by graphically plotting a gradual increase in proportion of arthropods collected over time (Bell et al., 2002; Macleod, Wratten, & Harwood, 1994).

Grizzly ELS 2500/8 is a cable powered, light weight (3.8 kg) leaf vacuum with nominal input voltage of 230 v, 50 Hz, maximum motor power of 2500 W, maximum air outlet speed of 160-270 km/h, and sound pressure level of 87 dB (Figure 1). This study thus reports the modification of Grizzly ELS 2500/8 leaf blower-vac for arthropod sampling and its field efficiency using watermelon as a case study.

Figure 1. Grizzly ELS 2500/ 8 leaf blower-vac (unmodified).

2. Material and Methods

2.1 Study site

The field study was conducted in the Research Farm of Federal University, Wukari, Nigeria (Latitude 7°51'N and Longitude 9°47'E) during the month of June, 2020. Wukari has an altitude of 187 m above sea level, an average annual temperature of 26.8°C, and an average annual rainfall of 1205 mm. The study area experiences a warm tropical climate characterized by dry and wet seasons. The wet season lasts from April to October peaking in June and September. Weeds commonly found in the study area includes; *Gomphrena celosoides* Mart., *Rottboellia cochinchinensis* (Lour.) Clayton, *Digitaria horizontalis* Willd., *Andropogon gayanus* Kunth, *Tridax procumbens* L., *Commelina benghalensis* L., *Imperata cylindrica* L. Raeuschel, *Ipomoea triloba* Linn., and *Cyperus rotundus* L. (Okrikata & Yusuf, 2016).

2.2 Modification of Grizzly ELS 2500/8 leaf vacuum for arthropod suction sampling

Figure 2 shows the modified machine. The steps below were followed for the modification;

1. The leaf blower-vac was procured as well as on/off switch, polyvinyl chloride (PVC) hose with internal diameter of 5 cm (0.0020 m^2 area), glue and screws.
2. The On/Off switch was connected to enable full throttle on starting the machine and the size of the leaf blower bag was reduced to 1/3 of its original size since the machine was redesigned for arthropod collection and not leaf intake (the initial main usage).
3. One end of the PVC hose)1.3 m long(was connected to the suction mouth of the machine with the aid of screws and glue to keep it fit and airtight while the other end serves as the intake nozzle.

Figure 2. Modified Grizzly ELS 2500/8.

2.2.1 Construction of the sampling enclosure

Figure 3 shows the sampling enclosure. The steps below were followed for its construction;

Suan Sunandha Science and Technology Journal

1. The bottom of a 35 cm high plastic bucket whose top internal diameter is 30 cm (0.0707 m^2 area) was cut off.
2. A 1 m long and 50 cm diameter nylon sleeve with mesh diameter of 0.5mm was prepared and attach to the upper side of the plastic bucket which faces the ground as shown in Figure 3.

Figure 3. Arthropod sampling enclosure.

2.2.2 Evaluating the efficiency of the modified arthropod suction sampler

The following procedures were followed to assess the efficiency of the modified machine as shown in Figures 4 and 5;
1. Two persons (one handling the sampling enclosure and the other; operating the devise) were used.
2. A sampling net (which had mesh size of 0.2 mm diameter, 35 cm long and tapered at the bottom) was inserted into the intake nozzle (5 cm diameter) overlapping its external flange and held in place by a rubber band (so as not to be sucked into the machine) as shown in Figure 4.
3. The machine was started (powered by a tiger generator, TG950) on maximum speed. The sampling enclosure was quickly, carefully and randomly placed on the plants in the field. The top of the bucket (now facing ground) was gently pushed into the soil in such a way as not to inflict damage on the plants while also ensuring that the sleeve is closed to prevent escape of trapped arthropods. Figure 5 shows how a sample was taken.
4. Sampling was taken by swirling the collection nozzle from the top to the bottom of the sampling enclosure and thereafter by sweeping the nozzle over the vegetation for a specified duration **(**A total of 20 samples were collected each with a sampling duration of 120 seconds**).**
5**.** Each of the 20 samples was made up of 6 sub-samples**.** The sampling duration of each sub-sample was 20 seconds **(**swirling the collection nozzle from top to bottom for 10 seconds and sweeping the nozzle over the plants for another 10 seconds**).** The sub-sampling procedure is completed by pulling the collection nozzle from the sleeve of the enclosure and then removing the rubber band holding the collection net after turning the machine upside down**.** The collection net was thereafter knotted quickly and pulled off the intake nozzle**.** All these were done while the machine was still running**.**
6**.** The arthropod samples collected were then killed in ethyl acetate in a killing jar and then preserved in 70**%** ethanol for subsequent sorting and counting in the field laboratory**.**
7**.** Procedures 3 - 5 above were repeated for the collection of subsequent samples**.**

Suan Sunandha Science and Technology Journal

Figure 4. Insertion of the collection net into the intake nozzle, and the inserted collection net.

Figure 5. Suction sampling procedure.

2.3 Data sorting and analysis

Collections in each sub-sample were sorted into arthropod orders and counted, and then pooled for each sample. The data were presented using box plots and bar charts (with standard error bars) generated using Paleontological Statistics Tool – Past$_3$ (Hammer, Harper, & Ryan, 2001). The financial estimate for the conversion of the leaf-vacuum to a suction sampler was computed using the average United Kingdom Pound (UK£) to Naira (₦) exchange rate during the study period (UK£1 = ₦515.75).

3. Results and Discussion

3.1 Efficiency of modified leaf vacuum in suction sampling and arthropods collected

The sound level of Grizzly ELS 2500/8 leaf blower-vac is 87 dB. Though, not extremely high, this sound level can disturb and make highly sensitive arthropod species to fly away. Hence, the use of a sampling enclosure in conjunction with the suction machine in the current study as recommended by Zou et al. (2016) is apt.

A total of 427 individuals across 10 arthropod orders were collected from watermelon plants which were at their early fruiting stage in the study area. Complete extraction of arthropods was achieved in all samples after the 6th sub-sample was collected (total sampling duration of 120 seconds). This was evident as careful visual observation of

Suan Sunandha Science and Technology Journal

the sampling enclosures revealed that no arthropod was left thereafter. Hence, the proportion of arthropods extracted within the 120 seconds sampling period was 100% (Figure 6).

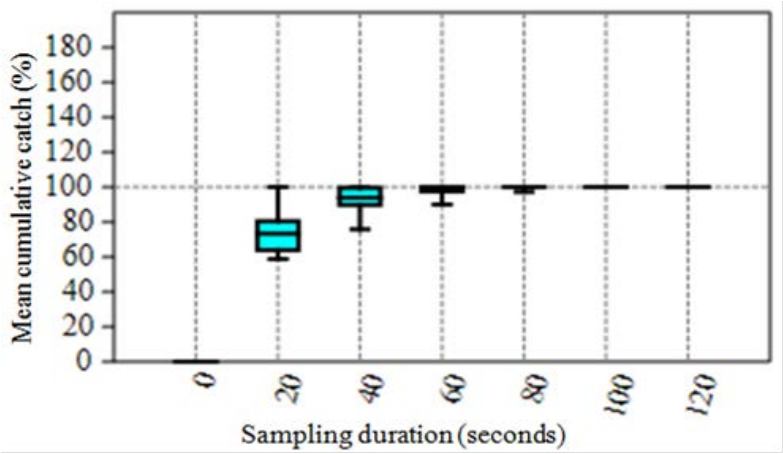

Figure 6. Cumulative arthropod collection over sampling duration of 120 seconds (Error bars indicates standard errors).

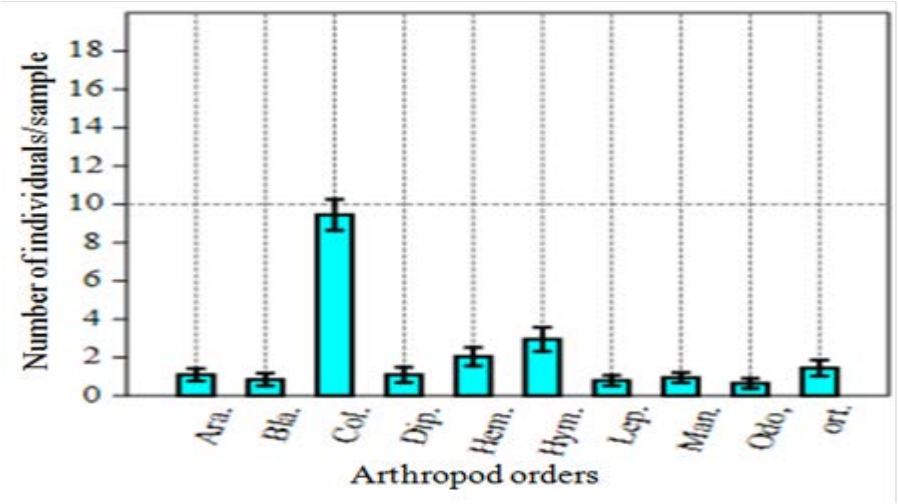

Figure 7. Average number of individuals within an arthropod order collected from 0.0707 m^2 area occupied by watermelon using a suction machine with intake nozzle area of 0.0020 m^2 (Error bars indicates standard errors; **Ara**. – Araneae; **Bla**. – Blattodea; **Col**. – Coleoptera; **Dip**. – Diptera; **Hem**. – Hemiptera; **Hym**. – Hymenoptera; **Lep**. – Lepidoptera; **Man**. – Mantodea; **Odo**. – Odonata; **Ort**. - Orthoptera).

Suan Sunandha Science and Technology Journal

The cumulative collection was 74.03%, 92.31%, 98.33%, 99.67% and 100% at 20, 40, 60, 80 and 100 seconds, respectively. The most abundant order was Coleoptera (44.26% relative abundance), and the least was Odonata (3.04% relative abundance) (Figure 7). The mean number of individuals per sample was 21.35±5.67.

That at 20 seconds sampling, about ¾ of the arthropod population was extracted is indicative of the efficiency of the machine which can also be of advantage if deployed as a non-chemical pest management tool. The current finding buttresses those of Macleod et al. (1994) and Bell et al. (2002) who showed that a fivefold increase in sampling duration hardly enhances arthropod catch. The current results cannot be a basis for recommending sampling duration for watermelon or any other plant for that matter as there are other known factors that can influence sampling duration and these include; suction power, nozzle diameter, complexity of vegetation structure, characteristics of the target organisms, and the weather (Sanders & Entling, 2011).

Suction samplers have been reported to be less disposed to error incidental to users as noticeable in visual assessment and sweep netting. As such data collected with them are more amenable to statistical analyses. It is also faster, requiring less effort and less, if at all destructive of the collected arthropods. Their efficiencies have been reported to be enhanced when used together with sampling enclosures (Holtkamps & Thompson, 1985) . The diameter of the intake nozzle could impact on sampling efficiency as wider diameters evidently suppress suction capacity. Unlike some D-vacs with about 36 cm intake nozzle diameter and some petrol driven samplers with 8-12 cm, the current modification here reported has an intake nozzle diameter of 5 cm. This may have also contributed to its high efficiency. However, one key drawback of suction samplers remains their inefficiency in wet weather or heavy dews on vegetation (Sunderland et al. , 1995).

Unlike battery powered leaf blower-vac which are limited in running time based on battery life, this equipment is cable powered and can be powered by a portable generator and as such have a longer running time depending largely on the source of power supply, in this case the generator. A test-run was conducted for 20 minutes at maximum/full speed without any negative effect or heating of the machine. This indicates that the machine can run much longer without any hitch.

3.2 Cost implication of the modified leaf vacuum

Table 1 shows the financial estimate of the conversion of the leaf blower-vac to arthropod suction sampler. The conversion technique was not high skill requiring and the overall cost was between £180 – 200 – shipping, and value added tax (VAT) inclusive.

While the current devalued status of Nigerian Naira vis-à-vis United Kingdom Pounds coupled with the current high shipping cost, economic impact of Covid-19 pandemic, and some other global and/or national economic indices may have impacted on the current cost of the blower-vac, it can be stated that overall, it is cheaper and more affordable for researchers and commercial farmers in developing countries when compared to D-vac and many other modern samplers. Even though D-vacs are still used widely, particularly, in the developed countries (Munyaneza, Crosslin, Upton, & Buchman, 2010), they are relatively more expensive to procure, have limited suction force, are heavier to carry, and bears higher maintenance requirements (Elliott et al., 2006).

The modified Grizzly blower-vac weighed 4.6 kg (original weight, 3.8 kg) and this makes for easier handling as it is far less heavy than the D-vac samplers which weighs up to 23 kg and even some modified petrol driven samplers that weighs ≈ 6 kg and above (Arnold, Needham, & Stevenson, 1973; Okrikata et al., 2019). When compared with earlier modified leaf vacuum (Arida & Heong, 1992; Domingo & Schoenly, 1998; Zou et al., 2016), the one in the current report seems to be the easiest to adopt as it does not require special expertise or skills and the materials used are also readily available. Therefore, with little experience, it can be coupled within an hour if the needed materials are on ground.

Table 1. Cost of converting Grizzly ELS 2500/8 leaf blower-vac to an arthropod suction sampler*.

Equipment/Materials	Cost (UK£)
Grizzly ELS 2500/8 blower-vac	160 - 180**
1.3 metre coiled polyvinyl chloride (PVC) hose	≈ 5
Fastening materials (500 ml Glue and 4 Screws), and On/Off switch	≈ 4
Plastic for sampling enclosure	≈ 3
Netting materials and sewing	≈ 5
Miscellaneous	3
Estimated Total	**180 - 200**

Exchange rate: UK£1 = ₦515.75

*Accessories inclusive

**Current shipping cost and value added tax (VAT) inclusive

Suan Sunandha Science and Technology Journal

4. Conclusion

The need for efficient and effective suction sampling technique was highlighted. The traditional D-vac sampler and many modern suction samplers have obvious deficiencies. The modified Grizzly ELS 2500/8 leaf vacuum here reported was largely efficient and effective as it is lighter, extracted high proportion of arthropods within a short sampling duration, easier to remodel, and cheaper. These factors will make accessibility particularly, for researchers and farmers in developing countries easier. It is therefore recommended for their use as a suitable alternative and also for consideration as a non-chemical pest management tool.

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Conflict of Interest

The authors do not report any financial or personal connections with other persons or organizations (except, TETFund which has been duly acknowledged), which might negatively affect the contents of this publication and/or claim authorship rights to this publication.

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6. References

Arida, G., & Heong, K. **(**1992). Blower-Vac: A new suction apparatus for sampling rice arthropods. *International Rice Research Newsletter*, *17*, 30-31.

Arnold, A. J., Needham, P. H., & Stevenson, J. H. (1973). A self-powered portable insect suction sampler and its use to assess the effects of azinphos methyl and endosulfan on blossom beetle populations on oil seed rape. *Annals of Applied Biology*, *75*, 229-233. doi:10.1111/j.1744.7348.1973.tb07302.x

Bell, J. R., Wheater, C. P., Henderson, R., & Cullen, W. R. (2002). Testing the efficiency of suction samplers (G-vacs) on spiders: The effect of increasing nozzle size and suction time. In S. Toft, & N. Scharff (Eds.), *European Arachnology 2000* (pp. 285-290). Aarhus, Denmark: Aarhus University Press.

Boiteau, G., Misener, G. C., Singh, R. P., & Bernard, G. (1992). Evaluation of a vacuum collector for insect pest control in potato. *American Potato Journal*, *69*, 157-166. doi:10.1007/BF02856547

Buffington, M. L., & Redak, R. A. (1998). A comparison of vacuum sampling versus sweep-netting for arthropod biodiversity measurements in California coastal sage scrub. *Journal of Insect Conservation*, *2*, 99-106. doi:10.1023/A:1009653021706

Cherrill, A. (2015). Suction sampling of grassland invertebrates using the G-vac**:** Quantifying and avoiding peripheral suction effects**.** *European Journal of Entomology*, *112*(3), 520-524. doi:10.14411/eje.2015.058

Domingo, I., & Schoenly, K. G. (1998). An improved suction apparatus for sampling invertebrate communities in flooded rice. *International Rice Research Notes*, *23*, 38-39.

Elliott, N. C., Tao, F. L., Fuentes-Granados, R., Giles, K. L., Elliott, D. T., Greenstone, M. H., … Royer, T. A. (2006). D-vac sampling for predatory arthropods in winter wheat. *Biological Control*, *38*, 325-330. doi:10.1016/j.biocontrol.2006.04.017

Grootaert, P., Pollet, M., Dekoninck, W., & van Achterberg, C. (2010). Sampling insects: General techniques, strategies and remarks. In J. Eymann, J. Degreef, Ch. Häuser, J. C. Monje, Y. Samyn, & D. VandenSpiegel (Eds.), *Manual on field recording techniques and protocols for all taxa biodiversity inventories and monitoring* (pp. 377-399). Belgium: Abc Taxa.

Hammer, O., Harper, D. A. T., & Ryan, P. D. (2001). PAST: Paleontological statistics software package for education and data analysis. *Palaeontologia Electronica*, *4*, 1-9.

Hand, S. C. (1986). The capture efficiency of the Dietrick vacuum insect net for aphids on grasses and cereals. *Annals of Applied Biology*, *108*, 233-241. doi:10.1111/j.1744-7348.1986.tb07645.x

Suan Sunandha Science and Technology Journal

Harper, C. A., & Guynn, D. C. (1998). A terrestrial vacuum sampler for macroinvertebrates. *Wildlife Society Bulletin*, *26*(2), 302-306.

Holtkamp, R. H., & Thompson, J. I. (1985). A lightweight, self-contained insect suction sampler. *Australian Journal of Entomology*, *24*, 301-302. doi:10.1111/j.1440-6055.1985.tb00247.x

Lima, C. H. O., Sarmento, R. A., Rosado, J. F., Silveira, M. C. A. C., Santos, G. R., Pedro-Neto, M., … Picanço, M. C. (2014). Efficiency and economic feasibility of pest control systems in watermelon cropping**.** *Journal of Economic Entomology*, *107*, 1118-1126. doi:10.1603/EC13512

Macleod, A., Wratten, S. D., & Harwood, R. W. J. (1994). The efficiency of a new lightweight suction sampler for sampling aphids and their predators in arable land. *Annals of Applied Biology*, *124*, 11-17. doi:10.1111/j.1744.7348.1994.tb04110.x

Munyaneza, J. E., Crosslin, J. M., Upton, J. E., & Buchman, J. L. (2010). Incidence of the beet leafhopper-transmitted virescence agent phytoplasma in local populations of the beet leafhopper, *Circulifer tenellus*, in Washington State. *Journal of Insect Science*, *10*, 1-10. doi:10.1673/031.010.1801

Okrikata, E., & Ogunwolu, E. O. (2019). Determination of the critical period of Cyper-diforce® treatment against arthropod fauna and productivity of watermelon. *Iraqi Journal of Science*, *60*(9), 1904-1919. doi:10.24996/ijs.2019. 60.9.3

Okrikata, E., Ogunwolu, E. O., & Odiaka, N. I. (2020). Effect of Cyper-diforce® application and variety on major insect pests of watermelon in the Southern Guinea Savanna of Nigeria. *Jordan Journal of Biological Sciences*, *13*, 107-115.

Okrikata, E., Ogunwolu, E. O., & Ukwela, M. U. (2019). Efficiency and economic viability of neem seed oil emulsion and Cyper-diforce® insecticides in watermelon production within the Nigerian Southern Guinea Savanna zone. *Journal of Crop Protection*, *8*, 81-101. doi:10.13140/RG.2.2.20031.36001

Okrikata, E., & Yusuf, O. A. (2016). Diversity and abundance of insects in Wukari, Taraba State, Nigeria. *International Biological and Biomedical Journal*, *2*, 156-166.

Reed, J. T., Adams, L. C., & Abel, C. A. (2010). Comparison of three insect sampling methods in sweet potato foliage in Mississippi**.** *Journal of Entomological Science*, *45*(2), 111-128. doi:10.18474/0749-8004-45.2.111

Sanders, D., & Entling, M. H. (2011). Large variation of suction sampling efficiency depending on arthropod groups, species traits and habitat properties. *Entomologia Experimentalis et Applicata*, *138*, 234-243. doi:10.1111/j.1570-7458.2020. 01094.x

Stewart, A. J. A., & Wright, A. F. (1995). A new inexpensive suction apparatus for sampling arthropods in grasslands. *Ecological Entomology***,** *20*, 98-102. doi:10.1111/j.1365-2311.1995.tb00434.x

Sunderland, K. D., De Snoo, G. R., Dinter, A., Hance, T., Helenius, J., Jepson, P., … Ulber, B. (1995). Density estimation for invertebrate predators in agroecosystems. In S. Toft, & W. Riedel (Eds.), *Arthropod natural enemies in arable land I: Density, spatial heterogeneity and dispersal* (pp. 133-162). Aarhus, Denmark: Aarhus University Press.

Thomas, D. B. (2012). Comparison of insect vacuums for sampling Asian citrus psyllid (Homoptera: Psyllidae) on citrus trees. *Southwestern Entomologist*, *37*, 55-60. doi:10.3958/059.037.0107

Zou, Y., van Telgen, M. D., Chen, J., Xiao, H., de Kraker, J., Bianchi, F. J., & van der Werf, W. (2016). Modification and application of a leaf blower-vac for field sampling of arthropods. *Journal of Visualized Experiments*, *114*, e54655. doi:10.3791/54655

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