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Squash (Cucurbita maxima D.) seed oil as thermal stabilizer for Polyvinyl Chloride (PVC)

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Abstract

Thermal stabilizers such as lead, a toxic heavy metal, are incorporated in polyvinyl chloride (PVC) which is thermally unstable. Due to environmental concerns, organic thermal stabilizers like squash seed oil were used in the study. Squash seed oil was extracted using improvised distillation. Two PVC flat sheet samples, with and without thermal stabilizers, were fabricated through incorporation of squash seed oil. Physical characterization, lead content determination, and thermal characterization were performed. Physical characterizations on the PVC samples were done by exposing the two samples in high temperatures. Yellowish brown stains formed in both PVC samples indicated that certain areas degraded due to long heat exposures. Absence of lead in the degraded samples was confirmed through US EPA Method 3050B, thus indicating nontoxicity of both the thermally stabilized and unstabilized PVCs. Thermal characterization was done through the improvisation of Differential Scanning Calorimeter. Results showed that the fabricated PVC was able to resist heat significantly longer by 168 seconds, compared to the unstabilized PVC by 81 seconds. Squash seed oil improved the thermal stability of PVC, therefore having the ability to replace the toxic thermal stabilizers.

Keywords: Environmental concerns, seed oil, Polyvinyl Chloride (PVC).

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1. Introduction

(Polyvinyl chloride (PVC) is widely used in the industry today, from the smallest children's toys to more complex objects like medical paraphernalia, sheathing material in cables, pipes, etc. It is one of the leading polymers for its industrial uses. PVC is incorporated with toxic heavy metals and/or organotin compounds to improve its weak thermal stability, but these materials have been severely criticized since it may bring up environmental concerns (Folarin & Sadiku, 2011), thus, PVC, when improperly disposed, lead to unwanted environmental concerns such as losses in biodiversity, changes in community composition, decreased growth and production rates for both plants and animals, and/or neurological effects on vertebrates (US EPA, 2014). These situations are likely to happen due to the improper waste disposal of local citizens.

PVC is a common commodity plastic, and its production is the third largest, after polyethylene and polypropylene (Yoshioka et al., 2008). It is one of the leading commercial polymers due to its versatility which is caused by the discovery of thermal stabilizers (Folarin et al., 2012). However, without the thermal stabilizer, the low thermal stability of PVC is one of the inherent problems associated with the manufacture and the use of this polymer (Okiemen, 2002). PVC, when exposed at extremely high temperature, degrade by thermal dehydrochlorination accompanied by secondary reactions such as chain scission, cross-liking, cyclisation, etc. and becomes discoloured due to formation of conjugated double bond in polymer chain (Toliwal & Patel, 2009), thus claiming thermal stabilizers as essential components in making PVC.

Currently, the main classes of thermal stabilizers used are lead salts, metal soaps and organotin compounds, but in previous research studies, these were found to have disadvantages in terms of toxicity, environmental pollution, and/or are costly. In fact, calcium and zinc of some seed oils have been investigated and proven to be safe thermal stabilizers for PVC (Folarin, 2008). As a result of the worldwide increase in thermal awareness, attention is currently being focused on thermal stabilizers that are non-toxic and environmental-friendly (Bao et al., 2008).

Squash, Cucurbita maxima D. is classified as an organic matter. Organic matters are considered environmental-friendly since these materials decompose in a short span of time. Although the decomposition rate may vary due to different factors, organic matters still decompose faster and less harmful to the environment, compared to heavy toxic metals which are incorporated in PVC.

A previous research on the mineral composition of squash seeds report that the calcium and zinc content squash seeds is 4.40Cmol/kg and 39.9 ppm, respectively. Meanwhile, pumpkins are known to be closely related to squash. A research on the mineral composition of pumpkin seed extract reports that the Calcium content of pumpkin seed was found to be 9.78mg/100g and that pumpkin seed presented a fairly high content of zinc (14.14±0.02mg/100g) (Elinge et al., 2012). Also, United States Department of Agriculture (USDA) released nutritional values of pumpkin seeds, stating that pumpkin seeds, when dried, result to a higher content of calcium and zinc with 46mg/100g and 7.81mg/100g, respectively (Livernais- Saettel, 2000).

This had led to extensive research and suggested squash seeds to be processed and tested as effective and environmental-friendly PVC thermal stabilizers instead of incorporating toxic heavy metals in PVC to improve its weak thermal stability. In light of using an organic material as a raw material, the researchers were able to produce a thermal stabilizer for PVC that is environmental friendly, which is beneficial to the environment and its biotic components. Hence, reducing factors that contribute to the destruction of the environment despite the improvement it shows technologically.

The study determined the feasibility of squash seed oil as thermal stabilizer for polyvinyl chloride (PVC).

Specifically, the study answered the following questions:

1. What were the characteristics of the PVC flat sheet wherein squash seed oil was incorporated in terms of:
   1.1 Thermal Characterization (Improvised Differential Scanning Calorimeter)
   1.2 Lead Content (US EPA Method 3050B)?
2. What were the visible indications that the PVC flat sheet started to degrade, in terms of:
   2.1 Colour,
   2.2 Smell,
   2.3 Phase Change?
3. At what time and temperature did the PVC flat sheet, wherein squash seed oil was incorporated, started to degrade?

1.1. Squash, Cucurbita maxima D. Seeds

Figure 1. Squash, *Cucurbita maxima D.* Seeds from Squash Fruit

Squash, *Cucurbita maxima D.* seeds are known to be healthy and excellent source of alpha carotene, beta carotene, calcium, magnesium, zinc, etc. (Moreno, 2015). Additionally, squash, melons, pumpkins, and cucumbers are all part of the Cucurbita family of vegetables, and they are all related to each other (Eclare, 2002).

Cucurbita seeds have been reported as good sources of protein, fats, carbohydrates and minerals. Despite the nutritional contents found Cucurbita seeds, a previous research conducted by Elinge et al., (2012) has shown that Cucurbita seeds do not only contain nutritional content. Squash and pumpkin seeds are also sources of other phyto-compounds in which at certain critical levels possess significant anti-nutritional compounds. As these seeds were analysed, results obtained were 5% moisture content, 5.50% ash, 38% crude lipid, 1% crude fibre, 27.48% crude protein, 28.03% of available carbohydrate and calorific value of 546 kilocalorie per 100 grams (Elinge et al., 2012).

Elemental analysis shows that potassium is the most abundant element in the sample, containing 273 milligrams per 100 grams and manganese as the least abundant, containing 0.06milligrams per 100 grams. The anti-nutritional parameters obtained per 100 grams35.06 milligrams of phytate, 0.02±0.10 milligrams oxalate, 0.22±0.04 milligrams hydrocyanic acid content and 2.27±002 milligrams of nitrate (Elinge et al., 2012). The results obtained from this research shows that if properly utilized, Cucurbita seeds can serve as good source of minerals.

The mineral composition and oil properties of Cucurbita seeds were discovered to be abundant. The most abundant mineral content was potassium, followed by phosphorus, sodium, calcium, magnesium, copper, zinc, iron, and manganese (Rezig et al., 2012).The mineral content of these seeds identified by Conde Nast (2014) are calcium (35.2milligrams), iron (2.1milligrams), magnesium (168milligrams), phosphorus (58.9 milligrams), potassium (588milligrams), sodium (11.5milligrams), zinc (6.6milligrams), copper (0.4milligrams) and manganese (0.3milligrams).Meanwhile, no selenium and fluoride were detected. In a similar study, Elinge et al., (2012) cited Payne's research focusing on the calcium content of the Cucurbita seeds. It was found that there are 9.78 of calcium content per 100 grams of Cucurbita seeds.

In Wiley's research (2002), Cucurbita seeds have presented a fairly high value for zinc (14.14±0.02milligrams/100gram). Zinc improved the fusion of the plastisols without any additive and it is stable at much higher temperatures. As zinc was present simultaneously in plastisol, it has been reported that zinc increased the thermal stability of the plastigels (Wiley, 2002). In some cases, zinc is used with alumina trihydrate to form a glass-like substance which inhibits polymer degradation. Zinc has also been reported to be effective in enhancing the flame-inhibition of chlorine, as studied by Kirk-Othmer (2004). Zinc borate increases flame resistance but it is not as effective as antimony oxide. However, when zinc is combined with antimony oxide, it will obtain equivalent effects and in some instances, this may improve effects over what can be obtained using either of the two synergists alone.

Meanwhile, a research conducted by Hamed et al., (2008) focused on the mineral composition of Cucurbita seeds that it is rich in minerals especially calcium. An experiment was held to compute the total (milligrams per 100 grams) and extractable (%) minerals of processed pumpkin seeds. Calcium had a total of 152.50 milligramsper 100 grams and 77% extractable minerals; a total of 134.00 milligrams per 100 gramsand 84% extractable minerals. This study showed that pumpkin seeds are rich in minerals (Hamed et al., 2008).

Another study showed that Cucurbita seeds are a good source of high nutritional and mineral content. The evidence of high nutritional content was proteins, lipids, fibers and carbohydrates. The minerals that were present were magnesium, calcium, zinc, phosphorus and iron (Kwiri, 2014). Petkova et al., (2015) stated in their research that Cucurbita seeds are used in many cultures all over the world. These seeds are by- products of the numerous food industries and are considered as valuable sources of biological components namely oils, proteins, carbohydrates, vitamins and microelements. Additionally, Ardabili et al.'s study (2011) proved that Cucurbita seed oil can be used in cooking. Ardabili et al.'s study concluded that the physicochemical properties of Cucurbita seeds show that it lies in the linoleic-oleic group such as corn, sesame and sunflower, thereby considering Cucurbita seed oil as a valuable source of oil that can be used as cooking oil. The contents of oil and protein seeds obtained from the seeds were 37.8% to 50% and 24.3% to 41.6%, respectively (Achu et al., 2005).

1.2. Thermal Stabilizers

In recent period, considerable efforts were exerted in order to find solutions in making PVC thermally stable, so that it can be used at high temperature. When PVC was discovered in 1912, it was brittle and was thermally unstable that companies using this product eventually stopped paying fees to manage its patent. In the preceding years, the discoveries of white lead also lead to the discovery of providing thermal stability in PVC-the discovery of thermal stabilizers.

Figure 2. Squash Seed Oil

Thermal stabilizers portray an essential role to PVC. The necessary protection needed by these PVCs in order to not decompose at a high temperature is provided by these stabilizers. Without this, PVC is thermally unstable during processing which requires exposure to above 1600 ^{o}C. Thermal stabilizers used in different studies were either in forms of metal carboxylates, soaps, pulverized or liquefied. The nature of anions has predominant effect on thermal stability. By scavenging HCl, the thermal stability of autocatalytic degradation of PVC can be delayed. This efficiency is mainly dependent on intercalated anion as well as adsorption capacity of the material surfaces (Gupta, 2008).

A review on potential thermal stabilizers for PVC has studied organic and inorganic compounds such as N-substituted maleimides, carbazole, barbituric acid, hydrotalcite, layered double hydroxide, inorganic salts, etc. These were synthesized in different ratios, were tested, and scientifically proven to be effective thermal stabilizers for PVC. These compounds' induction period was measured, during which no detectable amount of hydrogen chloride gas could be observed. Also, rate of dehydrochlorination and extent of discoloration were measured. Results show that these compounds are effective and environmental- friendly thermal stabilizers for PVC and most of the compounds exceeded the efficiency of ordinary toxic heavy-metal based thermal stabilizers (Folarin & Sadiku, 2011).

Lead-based stabilizers are not preferred since these results to physiological hazards when added to packaging materials, toys, pipes, etc. Layered double hydroxides (LDH) have been tested by Gupta et al. (2008), and LDH is now considered as new emerging class for PVC, in replacing toxic and environmentally hazardous class of heavy metals. This research work reports the preparation, characterization and evaluation of metal carboxylates from fixed oils that can function as composition for stabilizing halogen-containing polymer.

A previous research by Dr. Julius and Bamiji focused on the preparation, characterization and evaluation of metal carboxylates from fixed oils that can function as composition for stabilizing hydrogen polymer. The sample oils and the hydrolyzed fatty acids obtained were characterized. All chemicals used for this experiment are of analytical grade (Sigmoid and Merck) and the weighing balance used was mettle balance model AE 160. The physicochemical properties of the variety of vegetable oils have been obtained. Furthermore, the results show the difference in color and state. Three were liquid; one was semi-solid, including the highest percentage of 2n after carbonation. The results obtained from this study could be used as baseline data to develop a good micro emulsion stabilizer from the oils examined for the formulation of heat and chemical resistant halogen containing polymers (Julius & Bamiji, 2014).

Okiemen's study (2012) focused on epoxidised Rubber seed oil and metal soaps of the oil which were processed, and were added to the PVC samples. This study evaluated the epoxidised rubber seed oil as thermal stabilizer for PVCs. Results obtained from the intrinsic viscosity and levels of unsaturation shows that the metal soaps of the epoxidised rubber seed oil may be used as effective thermal stabilizer for PVC; thereby concluding that this study has shown that rubber seed oil is an effective thermal stabilizer for PVC. In a previous research focusing on *Jatrophamultifida* seed oil (JSO), JSO itself and effects of its metal soaps, including epoxides, on the thermal degradation of PVC have been reported. The seed oil was utilized and physio-chemical characteristics and fatty acid composition were identified. Results show that JSO can be classified as semi-drying oil. JSO are effective in reducing the extent of degradation of PVC and suppressing the dehydrochlorination rate of PVC (Okiemen, 2002).

Most of these researches focused on seed oils as thermal stabilizers of Polyvinyl chloride under inert condition. PVC is one of the most used plastic materials economic medium since the PVC products make life safer, more comfortable, and more pleasurable. PVC has an outstanding ratio of economic cost to performance; it permits people of all income levels across these important benefits. PVC made a huge impact in our everyday life and they are all around us, from roofing membranes to credit cards. We can also see them from construction profiles to medical devices, from children's toys to pipes for water and gas. Other materials that PVC involves are as versatile or capable to satisfy such demanding specifications. This made PVC unclog creativity and innovation, making stand-in possibilities.

1.3. Polyvinyl Chloride (PVC)

Figure 3. Polyvinyl chloride (PVC) Flat Sheet

According to the study of U.S National Library of Medicine, PVC is an odourless and solid plastic. Commonly, PVC is white in colour but sometimes it can also be colourless or amber. PVC may also possess a form of white powder or pellets. They are made from vinyl chloride and the chemical formula of vinyl chloride is C2H3Cl. PVC is devised up of many vinyl chloride molecules that are linked together to form a polymer (C2H3Cl)n. PVC is also a thermoplastic material (are those that can be melted again and again). Nowadays, PVC is generally used in the construction sector. The raw materials that were used to create PVC are salt and oil.

According to British Plastics Federation (2015), PVC is a major plastics material which is mainly used in building, means of transportation, packaging, electrical applications and healthcare applications. PVC is very durable and it is considered as a long lasting construction material which can be used in a wide variety of applications. Due to its very nature, PVC is used widespread by many industries and provides numerous popular and necessary products (British Plastics Federation, 2015).

PVC contains polymers (Julius & Bamiji, 2014) and is thermally unstable during processing (Folarin & Sadiku, 2011); thus, PVC requires the use of thermal stabilizers. Widely known thermal stabilizers are incorporated with toxic heavy- metals and these, most likely, would result to unwanted environmental problems; hence, several organic and inorganic compounds that were tested and scientifically proven to be effective and a not too costly thermal stabilizer they would like to refer as "green thermal stabilizer". PVC thermal stabilizers are likely to evolve if progress shows within the testing of organic and inorganic compounds. Organic and inorganic compounds have the potential for providing environmentally friendly thermal stabilizers for PVC (Folarin & Sadiku, 2011).

While decomposition of PVC can be affected by other forms of energy, the most important by far in the practice is thermal decomposition. As decomposition starts to happen, a substantially colourless polymer becomes yellowish, then brown, and finally black. Pink, red, and even purple are not unknown. When decomposition occurs after the polymer has become compounded with additives, development of colours can be very patchy. The rates of decomposition and colour development are temperature-dependent; increasing temperature results to an increasing rate in decomposition, and increase in the colour development. The different stabilizers vary in their ability in reducing decompositions, and the heat stabilities of different compositions.

PVC, when exposed to extremely high temperature, degrades by thermal dehydrochlorination accompanied by secondary reactions, specifically chain scission, cross-linking, cyclisation, etc. and becomes discoloured (Toliwal & Patel, 2009). Due to the low stability of PVC, problems associated with the manufacture and use of the polymer continues to arise (Okiemen, 2002). PVC loses HCl and becomes colorless, thus, making the product change its effectiveness and also the chemical and physical properties of the polymer. PVC needs thermal stabilizers during processing in order to prevent thermal degradation of PVCs (Okiemen, 2002).

Squash is classified as an environmental-friendly material since it is organic that decomposes in a short span of time, once disposed of. The mineral composition of the seeds of this fruit reports that high values of calcium and zinc are present. In fact, various seed oils have been tested and proven effective and environmental-friendly thermal stabilizers for PVC.

2. Materials and Methods

The experiment was done by dividing the methodology in three phases as shown in figure 4.

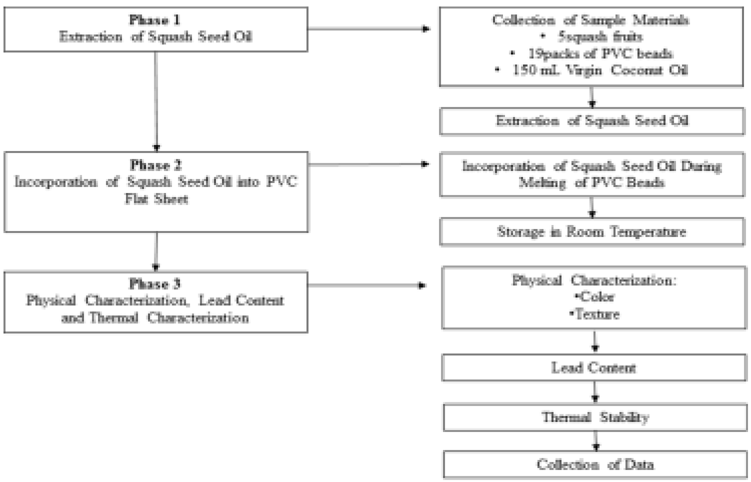

Figure 4. Schematic Diagram of the Methodology

2.1. Research Design

120 grams of squash seeds from five squash fruits were obtained, boiled, sun-dried and pounded. Using the distillation method, the squash seed oil extract was obtained, wherein the pounded squash seeds were combined with 150 milliliters of virgin coconut oil and 20 milliliters tap water. The mixture was continuously stirred for 15 minutes. The temperature in which the solvent (virgin coconut oil) separated with the squash seed oil was 79^{o}C. 237 milliliters of squash seed oil were obtained. 10 milliliters of squash seed oil was incorporated per PVC flat sheet, while the PVC beads were melted. The lead content of the PVC flat sheets was tested by SGS, meanwhile, the thermal characterization and the physical characterization of the PVC flat sheet were determined.

2.2. Phase 1-Extraction of Squash Seed Oil

2.2.1. Collection of Sample Materials

A total of five squash fruits were gathered from Pasay Palengke. 120 grams of seed were obtained from the squash fruits. A total of 19 packs of PVC beads were bought from Wilcon Builder's Depot, located at 2212 Chino Roces Ave, Makati City. The PVC beads were subjected to melting, and cooled, which resulted to the PVC flat sheet. 150 milliliters of virgin coconut oil was bought from South Star Drug, a local drugstore located near Mr. and Mrs. Pabinguit's residence in Pasay. The virgin coconut oil would be used during the distillation method.

2.2.2. Extraction of Squash Seed Oil

The squash seed oil was extracted using the distillation method. The seeds were boiled, sun-dried, pounded and mixed with the one-hundred fifty 150 milliliters virgin coconut oil and 20 milliliters tap water. The mixture was stirred continuously for 15 minutes while boiling. At 79^{o}C, the virgin coconut oil started to separate with the squash seed oil.

2.3. Phase 2-Incorporation of Squash Seed Oil into PVC Flat Sheet

2.3.1. Incorporating the Squash Seed Oil during Melting of PVC Beads

The rectangular pans were sterilized. The pans were used as the frame where two setups of PVC flat sheets were created. Setup A was the PVC flat sheet where the squash seed oil was incorporated; meanwhile, Setup B was the controlled variable wherein no squash seed oil was incorporated in the flat sheet. During the melting of PVC beads, a total of 10 milliliters of squash seed oil was gradually added in Setup A. Also, a roller was used to make the surface of the PVC flat sheet even.

2.3.2. Storage in Room Temperature

The PVC flat sheets were stored at room temperature of 27.7 ^{o}C. Both setups of the PVC flat sheet underwent the same process of storage.

2.4. Phase3-Physical Characterization, Lead Content and Thermal Characterization

2.4.1. Physical Characterization

The physical characteristics of both setups of the PVC flat sheets were observed in terms of the colour, the smell, and the phase change of the PVC flat sheets underwent after the product was made and after the improvised testing was performed.

2.4.2. Lead Content (US EPA Method 3050B)

The independent testing laboratory, SGS Philippines, Inc. performed the required parameters needed in the study. The PVC flat sheet sample was tested by the laboratory to detect the lead content of the PVC flat sheet. The lead content was measured using US EPA Method 3050B. The method was done through the strong acid digestion of sediments that could dissolve certain elements except for some that were bound in silicate structures such as lead (US EPA, 2014). This method has been written to provide two separate digestion procedures, one for the preparation of sediments, sludges, and soil samples for analysis by flame atomic absorption spectrometry (FLAA) or inductively coupled plasma atomic emission spectrometry (ICP-AES) and one for the preparation of sediments, sludges, and soil samples for analysis of samples by Graphite Furnace AA (GFAA) or inductively coupled plasma mass spectrometry (ICP-MS) (Kimbrough and Wakakuwa, 2000).

2.4.3. Thermal Characterization

The test was improvised, as advised by the Department of Science and Technology (DOST). In order to replace the Differential Scanning Calorimeter test, the apparatus that was advised to use was the hot plate, a sheet of aluminum foil and then a portion of the PVC, measuring one inch by one inch, placed on top of the foil. A weight (a rock) was placed on top of the PVC. The minimal movement of the rock indicated that the PVC was degrading. Three trials were performed on Setup A and Setup B. The time and temperature it took for the PVC flat sheet to degrade was recorded.

2.5. Collection of Data

The data obtained were used in determining the feasibility of squash seed oil as thermal stabilizer for polyvinyl chloride. For the first part of the testing which is the physical characterization, the data obtained were all qualitative. The results were all drawn by observing the smell, colour and phase change of the PVC flat sheet after the product was made and after the improvised testing was performed. SGS Philippines, Inc. conducted the second part of the testing which is the lead content, using US EPA Method 3050B. US EPA Method 3050B is a standardized testing conducted to prepare two setups of the PVC flat sheet for analysis by Graphite Furnace AA (GFAA) or inductively coupled plasma mass spectrometry (ICP-MS). Setup A is the flat sheet wherein the squash seed oil has been incorporated, and Setup B is the controlled variable, wherein no squash seed oil was incorporated in the flat sheet. GFAA or ICP-MS technique is used to detect lead in the PVC flat sheet. The method of this testing includes adding 10 milliliters of HCl to the sample and cover with a watch glass or vapor recovery device and places the sample on/in the heating source and reflux at 950^{o}C ± 50^{o}C for 15 minutes (Kimbrough and Wakakuwa, 2000).

3. Results and Discussion

The feasibility of squash seed oil as thermal stabilizer for PVC was determined by the visible indications shown by the PVC flat sheet in terms of color, smell and phase change, lead content and thermal characterization. Responses of the PVC flat sheet in the thermal characterization, specifically the time and temperature of Setup A where squash seed oil was incorporated and the controlled Setup, Setup B, where no squash seed oil was incorporated, were measured and statistically compared with each other using t-test.

3.1. Visible Indicators of Degradation of PVC Flat Sheets

The physical characteristics of the PVC flat sheet were observed after the product was made. Both setups of white PVC flat sheets possessed yellowish and brownish stains. This indicated that the areas of the PVC flat sheet degraded due to long exposure to heat during the process of incorporation of seed oil. Also, both Setups of PVC flat sheets were observed after the improvised testing in which the samples were degraded in the process called the improvised Differential Scanning Calorimeter (DSC). The PVC flat sheets of both setups emitted a foul smell. After degradation, the flat sheet turned into a semi- liquid. In a small period of time after degradation, the flat sheet returned to its solid state but has deformed.

Figure 5. PVC Flat Sheet Incorporated with Thermal Stabilizer (Setup A)

3.2. Lead Content

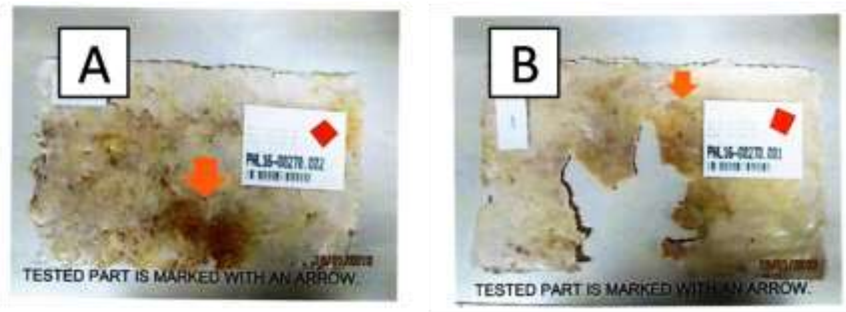

Figure 6. Tested PVC Flat Sheet by SGS Philippines, Inc.

Table 1. Comparison of lead content – setup A versus setup B versus commercialized PVC

PVC	Method	Lead Content
Setup A	US EPA Method 3050B	Not Detected
Setup B	US EPA Method 3050B	Not Detected
Commercialized/Reference		Detected

Table 1 exhibits the comparison among the three PVC samples, the PVC with thermal stabilizer, without thermal stabilizer and the commercialized PVC. Lead content is found in the commercialized PVC while lead content is not found on the PVC with and without thermal stabilizer. The products were analyzed through the use of US EPA Method 3050B in which the elements that are bound in silicate structures are not digested (US EPA, 2014).

3.3. Thermal Characterization

Figure 7. Setup of Improvised Differential Scanning Calorimeter

Table 2. Comparison of the time of degradation of PVC flat sheet – setup A versus setup B

Sample	Setup A (s)	Setup B (s)
1	176	64
2	204	97
3	124	82
Mean	168	8

Table 2 shows the time of degradation of Setup A and Setup B and there are three samples for each setup, and for each Setup, the mean was calculated. Results show that the mean for the time of degradation of Setup A is 168 seconds, which is higher compared to the time of degradation of Setup B which is 81 seconds. Setup A was able to withstand the heat longer because of the squash seed oil, which is composed of calcium and zinc. Wherein, calcium and zinc are used as thermal stabilizers in the PVC industry as of current period due to the thermal stabilizing property present in the calcium-zinc compound. This indicates that the squash seed oil is feasible as a thermal stabilizer for PVC.

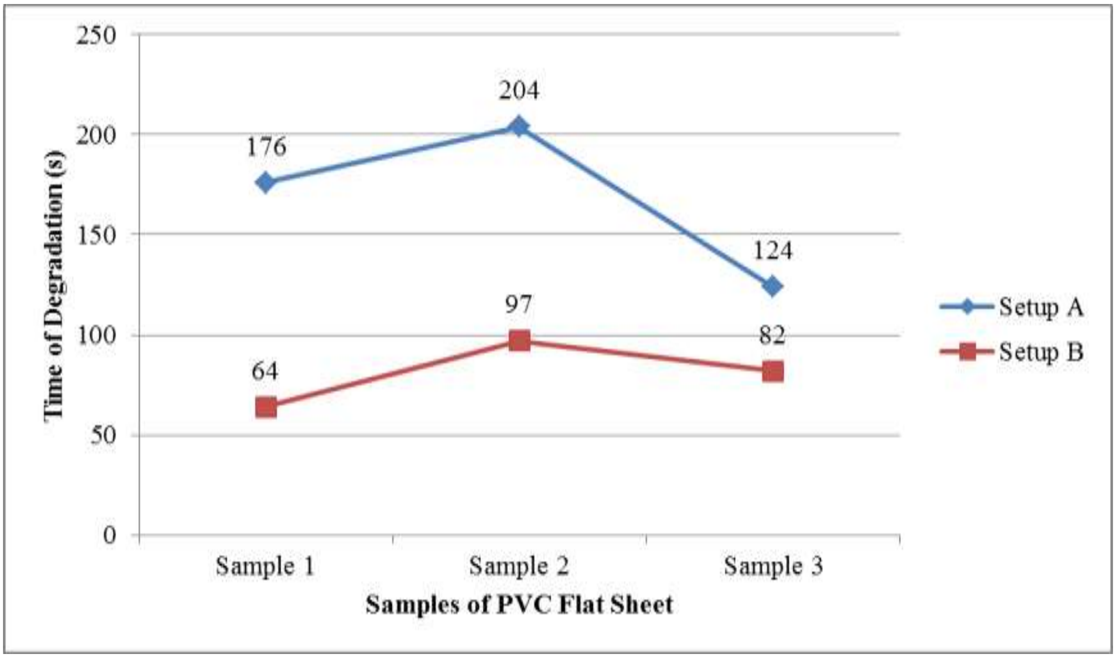

Figure 8. Comparison of the Time of Degradation of PVC Flat Sheet – Setup A versus Setup B

Figure 8 shows the time of degradation of Setup A and Setup B. Figure 8 exhibits the visual representation of the obtained data in Table 4. It shows that Setup A was able to withstand heat longer compared to Setup B due to the presence of calcium and zinc in squash seed oil.

Table 3. Comparison of the temperature of degradation of PVC flat sheet – setup A versus setup B

Sample	**Setup A (°C)**	**Setup B (°C)**
1	34	32
2	47	33
3	35	32.5
Mean	**38.67**	**32.5**

Table 3 shows the temperature of degradation of Setup A and Setup B. There are three samples for each setup, and for each setup, the mean is calculated. Results show that the mean for the temperature of degradation of Setup A is 38.67 °C, which is higher compared to the temperature of degradation of Setup B which is 32.5 °C.

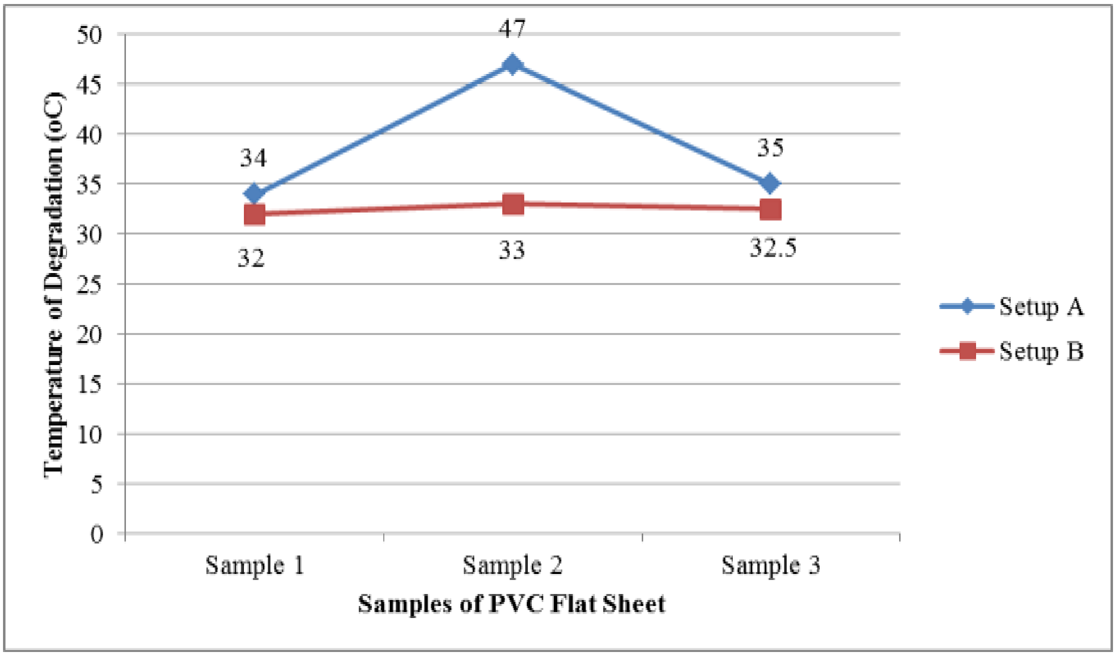

Figure 9. Comparison of the Temperature of Degradation of PVC Flat Sheet – Setup A versus Setup B

Figure 9 shows the time of degradation of Setup A and Setup B. Figure 9 exhibits the visual representation of the obtained data in Table 4. It shows that Setup A was able to resist heat longer compared to Setup B, for the same reason that calcium and zinc were present in the squash seed oil.

3.4. Interpretation of t score for time of degradation

$$t_{score} = 3.44$$

$$t_{value} = 4.31$$

$$\text{Reject if } |t_{score}| \geq |t_{value}|$$

Conclusion: Accept, because t_{score} (3.44) < t_{value}(4.31)

After statistically treating the recorded time of degradation of Setup A and Setup B obtained from the thermal characterization, the t_{score} and t_{value} were compared and analyzed.

The t_{score} (3.44) is less than the t_{value} (4.31), therefore, the study is feasible. The thermal stability of PVC was improved, using squash seed oil as thermal stabilizer, based on time of degradation.

3.5. Incorporation of t score for temperature of degradation

$$t_{score} = 1.460$$

$$t_{value} = 2.92$$

Reject if $|t_{score}| \geq |t_{value}|$

Conclusion: Accept, because t_{score} (1.460) < t_{value} (2.92)

After statistically treating the recorded temperature of degradation of Setup A and Setup B obtained from the thermal characterization, the t_{score} and t_{value} were compared and analyzed.The t_{score} (1.460) is less than the t_{value} (2.92), therefore, the study is feasible. The thermal stability of PVC was improved, using squash seed oil as thermal stabilizer, based on the temperature of degradation. The results obtained from recording the time and temperature of degradation through the thermal characterization test implies that the squash seed oil incorporated in PVC is feasible as a thermal stabilizer.

4. Conclusion

The squash seed oil has been proven efficient and effective thermal stabilizer for PVC. The study is feasible, given that the results from the improvised differential scanning calorimeter strongly indicate that there is an improvement in the thermal stability of PVC. Results of the improvised testing show that the product was able to withstand higher temperatures in a longer span of time. In line with improving the thermal stability of PVC, the lead content was also not detected in the product. The significance level was statistically treated using t-test and results indicate that the study is feasible given that the t_{score} based from the time and temperature of degradation of PVC were lesser than the t_{value}. The data obtained from the tests showed that the thermal stability of PVC was improved using the squash seed oil as thermal stabilizer. Furthermore, this would contribute to the reduction of usage of heavy toxic metals to improve the thermal stability of PVC in the industry.

5. Recommendations

The research was made to test the feasibility of squash seed oil as thermal stabilizer for PVC, however, it is recommended to utilize a different polymer in order to avoid health risks and have standardized tests since various institutions declined the researchers' proposal for testing purposes. Also, consider having an institution extract the seed oil, in order to get a pure seed oil.

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