Preparation and characterization of wet adhesives based on (poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate)/castor oil/styrene butadiene rubber) using gamma irradiation for trapping of reptiles and rodents

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Abstract
Wet adhesives from poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate), castor oil, and styrene butadiene rubber were prepared at variable compositions. These components were exposed to a certain range of irradiation dose for γ-rays. Wet adhesives were characterized by adhesion force, Fourier transform infrared, thermogravimetric analysis and derivative thermal gravimetric, gel permeation chromatography, proton nuclear magnetic resonance spectroscopy and scan electron microscopy. Results declared that dose and composition have significant effect on features of wet adhesives. Further, the adhesion force and thermal stability of wet adhesives improved by increasing the irradiation dose. Moreover, the adhesion force reached ~690 (kPa). The analysis of gel permeation chromatography showed that molecular weight of wet adhesive 48,921 (g/mol). The wet adhesives were exploited to trap reptiles and rodents. Through the results, it can be observed that the wet adhesives had good efficiency for trapping the reptiles and rodents. The results showed that the best sample of wet adhesive was from 98% of [poly (vinyl butyral-co-vinyl alcohol-co-vinyl (10%)/castor oil (90%)]) to [2% of styrene butadiene rubber] at 30 kGy In conclusion, this study referred that this type of wet adhesive has an excellent ability to adhere and trap of reptiles and rodents such as geckos and mice respectively. Consequently, these wet adhesives could be utilized in pilot scale.

Keyword Gamma irradiation · Wet adhesive · Composition · Trapping · Reptiles · Rodents

Introduction
The capacity of global market of adhesives absorbed more than 14.7 million tons in 2019, with the Asia Pacific region consumed for nearly 38% of the global share, then North America and Western Europe [1].The construction sector consumed more than 26% of the global need in 2019 [2]. Various applications of adhesives need adhesion to take place and continue in wet and underwater media. Nonetheless, the adhesion feature in wet media is clearly affected by the hydration film that grows on the surface of substrate, which forms a weak boundary layer and prohibits the adhesive from directly touching the substrate surface [3]. The restrictions of adhesives in wet media significantly limit their applications. Fortunately, inspiration can be found in nature. For example, mussels and sandcastle worms can bind powerfully to reefs in turbulent underwater media, and octopuses can firmly bind to surfaces and be in motion freely in wet media. In addition, amphibians can transfer flexibly in both wet and dry media. Among these, the excellent adhesion of mussels and sandcastle worms first attracted the interest of researchers [4]. Their adhesion abilities depend on the secretion of adhesive protein glues [5]. The fabrication of wet adhesives are in numerous ways, such as bionic adhesion, hydrogen bonding, electrostatic interaction, dynamic covalent bond, topological adhesion, and peelable adhesion [3]. The limitations of adhesives in wet conditions fundamentally limit their scale of applications. Fortunately,
inspiration can be found in nature. For example, mussels and sandcastle worms can adhere powerfully to reefs in turbulent underwater environments, and octopuses can firmly adhere to surfaces and move openly in wet media [3]. A catecholic amino acid found in the adhesive protein glue, 3,4-dihydroxy-l-phenylalanine, has been exteded to penetrate the hydration film and interact with the substrate surface, resulting in superior underwater adhesion [6]. Although significant progress has been made in the field of wet adhesives relied on the unique feature of catechol functional groups, the sensitivity of these groups to oxidation, pH, and temperature means that they are inconvenient for numerous applications, and there are restrictions to their durable adhesion and storage. To overwhelm these challenges, diverse non-catechol depended adhesives have been investigated such as nucleic acid/base and carboxyl-based adhesives; adhesives relating dynamic covalent bonding, topological adhesion, supramolecular self-assembly, and dry polymer crosslinking; as well as adhesives that mimic the adhesion seen in octopuses, geckos, tree frogs, and clingfish [7]. Lots of polyacrylamide-relied wet adhesives and solid–liquid mixed adhesives show good adhesion to wet tissue, but are not degradable and show poor biocompatibility. Although catechol-based adhesives are well-improved and show good biocompatibility when united with biocompatible polymers such as polyethylene glycol, lately it has been reported that catechol relied adhesives can create hydrogen peroxide as by-products during curing process, which has effect on the survival of cells in various applications. It was reported that some synthetic gecko adhesives with dry adhesive function have been prepared via polymers and multiwall carbon nanotubes, however it’s difficult to make a stable adhesion after operating of some continuous contact cycles and none have been shown to function under water [8]. Jin et al. fabricated the wet adhesives from Boron nitride nanosheet embedded bio-inspired wet adhesives [9]. The results showed that these wet adhesives may have wide applications in the biomedical and marine fields. Gao et al. synthesized the functional biomacromolecular wet adhesives with typical gel–sol transition and shear-thinning features [10]. The results exhibit considerable application potential in the biomedical field. It was reported that wet performance of biomimetic fibrillar adhesives was examined and displayed that the biomimetic systems enhanced the wet adhesive performance [11]. Lee et al. synthesized a reversible wet/dry adhesive inspired by mussels and geckos [12]. The results showed that this hybrid adhesive that combines the salient design elements of both gecko and mussel adhesives should be effective for reversible attachment to a diversity of surfaces in any environment. Recently, it was reported from literature that a given work was fabricated some tough adhesives [13], and topological adhesion [14]. The results declared that the steady compression of adherends was from 5 to 30 min to create stable adhesion [15, 16]. In radiation technology, the initiator, catalyst and cross linker is not needed because ionizing radiation is highly energetic and it can be deemed the γ-rays is responsible for initiation of crosslinking reactions [17]. Generally, the technology of gamma radiation relies basically on the use of high energy ionizing radiation to induce chemical and/or make biological changes and modifications in the respective component. According to the authors’ knowledge, the using gamma irradiation to synthesize wet adhesives is unique method. This is due to the cleanliness, low cost production, easiness, green and eco-friendly. In contrast to chemical methods of wet adhesives preparation that include impurities in final product could be leached during a certain application and causing toxicity, many tedious steps of preparation, high cost and not eco friendly. Furthermore, authors try to prepare non water–based wet adhesives to overcome the trackbacks of wet adhesives and widen their applications.

Therefore, the aim of this work is to develop of novel wet adhesives from poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate), castor oil, and styrene butadiene rubber. These components are subjected to different irradiation doses of gamma rays from 60Co as main source in order to prepare the wet adhesives. The wet adhesives are characterized by adhesion force, Fourier transform infrared (FTIR), thermogravimetric analysis and derivative thermal gravimetric (TGA-DTG), gel permeation chromatography (GPC), proton nuclear magnetic resonance spectroscopy (1H NMR) and scan electron microscopy (SEM). These wet adhesives are exploited in adhesion and trapping of reptiles and rodents such as geckos and mice, respectively.

**Experiments**

**Materials and methods**

Poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate) (average molecular weight: 50 kDa, CAS number: 27360–07-2) was supplied from Sigma-Aldrich Company, (USA). Styrene butadiene rubber (Commercial name BUNA™ SB 1502-Schkopau) was supplied from Sibur Company (Moscow, Russia). Castor oil was (CAS number: 8001–79-4) supplied from paint and chemical industry, PACHIN, (Egypt). The chemical structures of these substances are depicted in Fig. 1.

**Wet adhesive preparation**

Different mixture were prepared from poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate) (PVBA) and castor oil (O) utilizing a mechanical mixer at 85 °C for 30 min with speed 120 rpm until to make sure the mixing process of all
reactants were carried out well. The full recipe of preparation for wet adhesives is listed in Table 1. The these mixtures were exposed to wide range of irradiation dose (see Table 1). The outcome wet adhesives are extracted and casted on square cardboard 20 cm² to investigate their adhesion force. The best composition ratio among mixtures is 10/90 (g/g) of (PVBA/O). The choice of this composition in specific based on good results value of adhesion force obtained for 10/90 (g/g) of (PVBA/O) (later it will be seen in Fig. 3), having a problem of roll-around that needed to be improved. Therefore, the styrene butadiene rubber (SBR) was added to (PVBA/O) using mechanical mixer at room temperature for 40 min with speed 120 rpm until to sure the well mixing process was conducted well for different composition ratios as listed in Table 1. Then, the all outcome mixture (namely, PVBA/O & SBR) from mixing process are exposed to wide range of irradiation dose as listed with full details in Table 1. The extracted wet adhesives (10 ml) are poured onto square cardboard 20 cm² using to investigate their adhesion forces. Further, irradiation dose ranged from 0 to 50 kGy of irradiation dose rate ~0.9 kGy/h (cell type of gamma irradiation is an Indian Cell). A proposed reaction mechanism to prepare wet adhesive is shown in Fig. 2.

Figure 1: Chemical structures of a poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate), b castor oil and c styrene butadiene rubber

Characterization

Fourier transforms infrared spectroscopy (FTIR) is used to measure the wet adhesives by FTIR spectrometer (ATI Mattson-Genesis series, England). Infrared spectra were recorded in the range from 400 to 4000 cm⁻¹. The surface characteristic morphology of the wet adhesives was studied using scanning electron microscope (SEM) (Model ZEISSEVO15, UK). The thermal behavior of the wet adhesives was examined by applying thermogravimetric analysis (TGA) technique utilizing a TG-50 instrument from Shimadzu (Japan). The wet adhesives heated from room temperature up to 600 °C, with a heating rate of 10 °C/min. Measurements were taken under nitrogen gas at a flow rate of 20 ml/min. The wet adhesives were investigated by proton nuclear magnetic resonance (¹H-NMR) attached by the spectrometer Avance III 400 MHz (Bruker, Germany). All these measurement are conducted in microanalytical unit (faculty of pharmacy, Cairo University). Gel-permeation chromatography (GPC) refractive index detector, empower TM2 chromatography data software, flow 1 mL/min, mobile phase THF is used to determine the average molecular weight of wet adhesives.

Mechanical testing

The wet adhesive is poured on the surface of 1 cm of width×1 cm of length (note that the original dimensions of smooth card paper are 1 cm of width×10 cm of length). The above poured wet adhesive (0.1 ml) on 1 cm×1 cm was covered by 1 cm of width×10 cm of length. The covering scale from two sides is only on 1 cm×1 cm and wet adhesive is like a sandwich between two sides of papers. This wet adhesive is left for 5 min in the former position to let the two sides of papers sticking well on the wet adhesive. The values of wet adhesive ratios are listed in Table 1 and their corresponding irradiation dose from 0 to 50 kGy with dose rate ~0.9 kGy/h. The adhesion force is determined utilizing the mechanical tool. The measurements of the mechanical properties of wet adhesives were determined by a microprocessor controlled tensile testing apparatus of (Hung-Ta Model HT-9112, Taiwan).

Trapping rodents and reptiles

Glass sheet with dimensions (length 20 cm×width 30 cm×thickness 1 mm) were cleaned up thoroughly with distilled water followed by ethanol then was put on the clean bench. The clean glass sheets were balanced using water level measuring tool. The cardboard paper was put onto the clean surface of glass sheet and adjusted well to fit the glass sheet’s dimensions. The cardboard paper was adjusted on the surface of film applicator (Elcometer 3520 Baker Film Applicator). The wet adhesive was poured slowly onto the surface of film.
applied, the wet applicator was adjusted at 200 µm. The casted wet adhesive is left to spread and cover the whole cardboard paper surface (for 2 h to make sure the full spread and cover of card paper). Thereafter, the wet adhesive on card paper is left to be in open air for 24 h (open agricultural field on the ground to catch mice) and put on top of cupboard’s at home to trap geckos.

Table 1 Preparation conditions of wet adhesives

| Sample       | Composition ratio (g/g) | Miscibility | Dose (kGy) | Dose rate (kGy/h) | Coded sample  |
|--------------|-------------------------|-------------|------------|-------------------|---------------|
| PVBA/O       | 5/95                    | Thick liquid | 0         | ~0.9              | (PVBA/O-5/95)-0 |
|              |                         | Viscous     | 10        |                   | (PVBA/O-5/95)-10 |
|              |                         | Viscous     | 20        |                   | (PVBA/O-5/95)-20 |
|              |                         | Viscous     | 30        |                   | (PVBA/O-5/95)-30 |
|              |                         | Viscous     | 40        |                   | (PVBA/O-5/95)-40 |
|              |                         | Viscous     | 50        |                   | (PVBA/O-5/95)-50 |
| 10/90        |                        | Thick liquid | 0         |                   | (PVBA/O-10/90)-0 |
|              |                         | Viscous     | 10        |                   | (PVBA/O-10/90)-10 |
|              |                         | Viscous     | 20        |                   | (PVBA/O-10/90)-20 |
|              |                         | Viscous     | 30        |                   | (PVBA/O-10/90)-30 |
|              |                         | Viscous     | 40        |                   | (PVBA/O-10/90)-40 |
|              |                         | Viscous     | 50        |                   | (PVBA/O-10/90)-50 |
| 15/85        |                        | Thick liquid | 0         |                   | (PVBA/O-15/85)-0 |
|              |                         | Viscous     | 10        |                   | (PVBA/O-15/85)-10 |
|              |                         | Viscous     | 20        |                   | (PVBA/O-15/85)-20 |
|              |                         | Viscous     | 30        |                   | (PVBA/O-15/85)-30 |
|              |                         | Viscous     | 40        |                   | (PVBA/O-15/85)-40 |
|              |                         | Viscous     | 50        |                   | (PVBA/O-15/85)-50 |
| (PVBA/O)/SBR |                        | Thick liquid | 0         |                   | (PVBA/O-10/90)/SBR-99/1–0 |
| 99/1         |                         | Viscous     | 10        |                   | (PVBA/O-10/90)/SBR-99/1–10 |
|              |                         | Viscous     | 20        |                   | (PVBA/O-10/90)/SBR-99/1–20 |
|              |                         | Viscous     | 30        |                   | (PVBA/O-10/90)/SBR-99/1–30 |
|              |                         | Viscous     | 40        |                   | (PVBA/O-10/90)/SBR-99/1–40 |
|              |                         | Viscous     | 50        |                   | (PVBA/O-10/90)/SBR-99/1–50 |
| 98/2         |                        | Thick liquid | 0         |                   | (PVBA/O-10/90)/SBR-98/2–0 |
|              |                         | Viscous     | 10        |                   | (PVBA/O-10/90)/SBR-98/2–10 |
|              |                         | Viscous     | 20        |                   | (PVBA/O-10/90)/SBR-98/2–20 |
|              |                         | Viscous     | 30        |                   | (PVBA/O-10/90)/SBR-98/2–30 |
|              |                         | Viscous     | 40        |                   | (PVBA/O-10/90)/SBR-98/2–40 |
|              |                         | Viscous     | 50        |                   | (PVBA/O-10/90)/SBR-98/2–50 |
| 97/3         |                        | Thick liquid | 0         |                   | (PVBA/O-10/90)/SBR-97/3–0 |
|              |                         | Viscous     | 10        |                   | (PVBA/O-10/90)/SBR-97/3–10 |
|              |                         | Viscous     | 20        |                   | (PVBA/O-10/90)/SBR-97/3–20 |
|              |                         | Viscous     | 30        |                   | (PVBA/O-10/90)/SBR-97/3–30 |
|              |                         | Viscous     | 40        |                   | (PVBA/O-10/90)/SBR-97/3–40 |
|              |                         | Viscous     | 50        |                   | (PVBA/O-10/90)/SBR-97/3–50 |

Results and discussion

Effect of irradiation dose on adhesion force

The wet adhesives of poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate)/castor oil/styrene butadiene
Fig. 2 A proposed reaction mechanism of PVBA, O and SBR to form (PVBA/O/SBR) wet adhesives by gamma irradiation
Fig. 3 Effect of irradiation dose on adhesion force of a (PVBA/O-5/95), (PVBA/O-10/90), (PVBA/O-15/85) b (PVBA/O-10/90)/SBR-99/1, (PVBA/O-10/90)/SBR-98/2, (PVBA/O-10/90)/SBR-97/3 and c assembly of subfigures a & b
rubber can be easily synthesized by using gamma irradiation as shown in a proposed reaction mechanism as in Fig. 2. Figure 3a illustrates the influence of irradiation dose on adhesion forces of (PVBA/O-5/95), (PVBA/O-10/90) and (PVBA/O-15/85) wet adhesives. Overall, it is observed that the adhesion force increases by increasing the irradiation dose up to 30 kGy, then decreases. This irradiation dose of 30 kGy is the optimum dose along range of irradiation dose. Further, by increasing the PVBA content into the feeding composition, the adhesion force increases. Further, the optimum wet adhesive sample is (PVBA/O-10/90). This is due to the highest adhesion force of 588 (kPa) at 30 kGy. The sequential order of adhesion force at 30 kGy is (PVBA/O-5/95) < (PVBA/O-10/90) < (PVBA/O-15/90) wet adhesives and the corresponding values of this sequential order are 361, 370 and 588 (kPa), respectively. Therefore, the composition of PVBA/O-10/90 of wet adhesive considers a critical composition. It may be deduced that the irradiation dose of 30 kGy is optimum that causing the highest crosslinking density. Afterwards, the degradation process could occur and cause a decrement in the value of adhesion force. Figure 3b shows the effect of irradiation dose on the different compositions of (PVBA/O-10/90)/SBR-99/1, (PVBA/O-10/90)/SBR-98/2 and (PVBA/O-10/90)/SBR-97/3. Generally, it can be seen that by increasing the irradiation dose, the adhesion force increases up to 30 kGy, then the adhesion force decreases. This may be due to the crosslinking process that occurs up to 30 kGy then degradation process occurs after 30 kGy. Further, by increasing the SBR feeding into (PVBA/O-10/90) mixture, the adhesion force increases from (PVBA/O-10/90)/SBR-98/1 up to (PVBA/O-10/90)/SBR-98/2, then decreases for (PVBA/O-10/90)/SBR-98/3. This is assigned to the degradation process of (PVBA/O-10/90)/SBR-98/3 between (PVBA/O-10/90) and SBR at this specific ratio. Figure 3c shows the relationship between the adhesion force and irradiation dose of (PVBA/O-5/95), (PVBA/O-10/90), (PVBA/O-15/85), (PVBA/O-10/90)/SBR-99/1, (PVBA/O-10/90)/SBR-98/2 and (PVBA/O-10/90)/SBR-97/3. Generally, it can be observed that by increasing irradiation dose, the adhesion force increases for all wet adhesives. In addition, it can be noticed that the sequential order of adhesion force of all wet adhesives is (PVBA/O-10/90)/SBR-98/2 > (PVBA/O-10/90) > (PVBA/O-10/90)/SBR-97/3 > (PVBA/O-10/90)/SBR-99/1, (PVBA/O-10/90)/SBR-98/2 and (PVBA/O-10/90)/SBR-97/3. Generally, the peak of ester group (O–C(O)–C) appeared at 1243 cm⁻¹ and ordi-

FTIR spectra analysis

Figure 5 exposes the FTIR spectra of PVBA, O, (PVBA/O-10/90)-30 wet adhesive, SBR and (PVBA/O-10/90)/SBR-98/2–30 wet adhesive, respectively. Spectrum of PVBA shows the characteristic peaks are at 3446, 2978, 1143, 1082 and 820 cm⁻¹ correspond to O–H stretching (vinyl alcohol), C–H, C–O stretching of ether, C–O stretching and C–H bending of alcohol, accordingly [18]. Moreover, the peak is at 970 cm⁻¹ assigned to acetal function group of vinyl butyral [19]. Further, the antisymmetric bending vibration of CH₃ group is at 1460 cm⁻¹ and ordinarially overlapped with CH₂ scissoring at 1444 cm⁻¹. The peak of ester group (O–(C–O)–C) appeared at 1243 cm⁻¹ [20]. The peak appears at 1380 cm⁻¹ assigned to symmetric bending of CH₂ and in-plane deformation of C–OH [21].

The spectrum of O contains a broad peak appears at 3376 cm⁻¹ that corresponds to O––H stretching and the peaks appear at 2934 and 2863 cm⁻¹ assigned to –C––H stretching for long alkyl chain (i.e., characteristics of asymmetrical and symmetrical of aliphatic –CH₂ groups fatty acid hydrocarbon chain) [22]. The peaks are at 1725, 1488 and 1181 cm⁻¹ referred to C = O stretching of methoxy groups (-OCH₃), C = O and C = O stretching of O-CH₃ group, respectively [16, 23]. Overall, these results confirmed the presence of alkyl triglyceride oil [24]. The peak is at 3050 cm⁻¹ indicates to –CH₂ stretching vibrations of cis-double bond of unsaturation [25]. The peak appears at 1361 and 1270 cm⁻¹ are due to bending vibration of –CH₂ groups. The peak appears at 1089 cm⁻¹ corresponding to group of ester carbonyl [26]. The peak is at 940 cm⁻¹ illustrates the presence of –HC = CH₂(trans) bending out of plane. Nonetheless, the peak is at 750 cm⁻¹ is assigned to

Demonstration photos of wet adhesives

Figure 4a-g displays the demonstration photos of wet adhesive of (PVBA/O-10/90)/SBR-98/2–30 at different distance 2, 6.5 and 14 cm, respectively. It is seen that the adhesive content is as flexible strings and their density diminish gradually by increasing distance then almost disappear as shown in Fig. 4c. Figure 4d-g shows the demonstration photos of wet adhesive of (PVBA/O-10/90)/SBR-98/2–30 at different distance 4.5, 7.5, 14 and 18 cm, respectively. The observations indicate to that the adhesive content is as flexible strings featured with strong, dense and relative big at different distance. Further, this distance is bigger if compared to the distance of wet adhesive of (PVBA/O-10/90)-30 as described by red cycles. The wet adhesive of (PVBA/O-10/90)/SBR-98/2–30 (Fig. 4g) represents the strongest one that features with more strong, flexible, dense and relative big strings. Moreover, there is no damaging for the adhesive content of strings.
overlapping of −CH₂ rocking out of plane vibration of cis-disubstituted olefins, characteristic peaks of long chain fatty acids. The spectrum of (PVBA/O-10/90)-30 wet adhesive shows the reduction in intensity of OH peak is at 3395 cm⁻¹ and disappearing peak at 1611 cm⁻¹ were shown by arrows in the spectrum of (PVBA/O-10/90)-30 wet adhesive. Therefore, reaction occurs between two constituents of PVBA and O after exposing to γ-rays. The SBR shows the characteristic peaks are at 2915 and 2852 cm⁻¹ corresponded to the CH stretching of aromatic rings. The peak appears at 1604 cm⁻¹ corresponding to the stretching vibration of CH₂ and CH₃ groups. The peaks appear at 965 and 695 cm⁻¹ is due to presence of the aromatic C–C stretching. Others peaks appear at 910 and 756 cm⁻¹ were due to trans 1,4 structure and CH of single substituted benzene ring and CH out of plane deformation, respectively [27]. The peak appears at 3067 cm⁻¹ indicates to the existence of C-H stretches attached to phenyl ring. The peak appears at 1650 cm⁻¹ for C = C in phenyl ring. The peak of CH₂ group in-plain deformation into butadiene appears at 1444 cm⁻¹. The peak appears at 1372 cm⁻¹ for CH₂ wagging of butadiene [28]. Further, the spectrum of (PVBA/O-10/90)/SBR-98/2–30 wet adhesive indicates to the disappearance of 3067 cm⁻¹ of C-H stretches attached to phenyl ring, 1604 cm⁻¹ is due to the stretching vibration of the CH₂ and CH₃ and at 1492 cm⁻¹ of CH₂ in-plain deformation into butadiene as depicted by arrows in the spectrum of (PVBA/O-10/90)/SBR-98/2–30. Moreover, castor oil contains the triacylglycerol of ricinoleic acid, rooted from the family Ricinus communis, and consisted of a fatty acid having a cis-unsaturation at carbon 10, 11 and a hydroxyl at carbon 13. In contrast to the most vegetable oils, in ricinoleic acid, there are three sites that can suffer chemical modifications or changes: hydroxyl, unsaturation and carboxyl [29]. Moreover, the potentiality

Fig. 4 Demonstration photos of a-c (PVBA/O-10/90)-30 and d-g (PVBA/O-10/90)/SBR-98/2–30 wet adhesive at different distance of room temperature

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Fig. 5 FTIR spectra of PVBA, O, (PVBA/O-10/90)-30 wet adhesive, SBR and (PVBA/O-10/90)/SBR-98/2–30 wet adhesive.
of crosslinking occurs between at unsaturation of carbon 9 and 10 of O. Therefore, it can be deduced that possibility of graft copolymerization reaction occurs on the backbone of SBR and (PVBA/O-10/90) after exposing to γ-rays. In conclusion, the graft copolymerization of starting reactants are among unsaturation of carbon 9 and 10 of O, C-H bending of alcohol of PVBA and C-H stretches attached to phenyl ring of SBR as proposed reaction mechanism in Fig. 2.

**1H-NMR spectrum analysis**

Figure 6 displays the 1H-NMR spectrum of (PVBA/O-10/90)/SBR-98/2–30 wet adhesive. This sample of wet adhesive is chosen according to the best adhesion force among wet adhesives. The group of butyral methyl CH₃ is at 0.95 ppm. The butyral and alcohol methylene CH₂ appears at 1.2–1.8 ppm. Meso-butyral dioxymethine O–CH–O is at 4.6 ppm. Racemic butyral dioxymethine O–CH–O appears at 4.8 ppm. Methine butyral CH and vinyl OH appears at 3.6–4.4 ppm [30]. Regarding to the castor oil, the tertiary proton of -CH₂CHCH₂- backbone (namely, methane proton glycerol structure and cis-double bonds) is at δ = 5.2–5.3 ppm. Moreover, the methylene proton of -CH₂CHCH₂- backbone appears at δ = 4.1–4.4 ppm, and the tertiary hydrogen adjacent to the hydroxyl proton in fatty acid chain appears at δ = 3.5–3.6 ppm [31]. The major part of double bond of ricinoleic acid appears at δ = 5.4–5.5 ppm [32]. The 1H NMR spectrum of SBR (Fig. 6) illustrates a signal at δ = 5.4 ppm that is assigned to trans- and cis-1,4 hydrogen and a signal is at δ = 4.9 ppm of two terminally vinylic hydrogen [33]. The region is from 0.9 to 2.8 ppm refers the presence of aliphatic protons. The peaks in the region is from 6.8 to 7.2 ppm confirm the presence of aromatic protons [34]. Therefore, the structures of PVBA, O and SBR are found in (PVBA/O-10/90)/SBR-98/2–30 wet adhesive. However, the wet adhesive of (PVBA/O-10/90)/SBR-98/2–30 formed, peaks for residues of starting reactants are still embedded in the final product of wet adhesive and shown in spectrum of 1H NMR.

**GPC analysis**

The (PVBA/O-10/90)/SBR-98/2–30 wet adhesive is analyzed by using GPC as listed in Table 2. This wet adhesive is chosen to be representative sample is due to the best adhesion force (689 kPa) among all wet adhesive samples. Through the results into the Table 2, it is noticed that the values of the Mn, Mw and polydispersity are ~ 64 kD, ~ 78 kD and ~ 1.4, respectively. Therefore, due to the value of polydispersity it can be deduced that the wet adhesive of (PVBA/O-10/90)/SBR-98/2–30 has broad molecular weight distributions. Therefore, the extra chains formed of wet adhesive. These extra chains that featured with the

| Retention time (min) | Mn<sup>a</sup> | Mw<sup>b</sup> | Polydispersity |
|----------------------|---------------|---------------|----------------|
| 22.1                 | 35,358        | 48,921        | ~ 1.4          |

<sup>a</sup> Mn refers to number average molecular weight
<sup>b</sup> Mw refers to weight average molecular weight

![Fig. 6 1H-NMR spectrum of (PVBA/O-10/90)/SBR-98/2–30 wet adhesive](image)
heterogeneity in crosslinking, dense network formation, hyper branching and more random arrangement in structure. These values indicate to the interactions of PVBA, O and SBR together to form tertiary polymeric wet adhesive. Additionally, more parameters from GPC analysis are found in Fig. S1, Fig. S2 and Table S1 (Supplementary Data File). Moreover, The SEM photomicrographs are existed in Fig. S3 (Supplementary Data File).

Thermal analysis

Figure 7 illustrates the TGA thermograms and derivative thermal gravimetric (DTG) curves of PVBA/O-10/90)/SBR-98/2–0, (PVBA/O-10/90)/SBR-98/2–10, and (PVBA/O-10/90)/SBR-98/2–30 wet adhesives. Overall, it can be seen from TGA thermograms that by increasing the irradiation dose, the thermal stability of wet adhesives increases. This is due to the augmenting the crosslinking. Further, the DTG curves exposes that the thermal decomposition of all wet adhesives occurs at three stages. During the first phase, only a minimal weight change was observed during this induction period. The thermogram displays that 1–3% weight loss of wet adhesives occurs around 280 °C. A rapid weight change was observed during the second phase. The maximum degradation rate occurs at a temperature of about 361 °C where the rate of weight decreases to the maximum up to this point. This is assigned to thermal decomposition of molecular chain and crosslinking structure of the polymer. Moreover, the third stage occurs at 491 °C. The curve flatter at 558 °C exposes that no further conversion occurs. The DTG curve illustrates a strong evidence for the three thermal degradation stages. Further, by comparing the thermograms for all wet adhesives at various radiation doses, it is noticed that the thermal stability increases significantly by increase in the radiation dose.

Hence it can be concluded that the best wet adhesive is (PVBA/O-10/90)/SBR-98/2–50 for resistance of thermal decomposition among wet adhesives.

Efficiency of wet adhesive

Figure 8 illustrates the efficiency of (PVBA/O-10/90)/SBR-98/2–30 wet adhesive after passing 6 month. The value of adhesion force after one month (~690 kPa) is approximately the same value after 6 month (~688 kPa). Consequently, it was deduced that the efficiency of (PVBA/O-10/90)/SBR-98/2–30 wet adhesive is good after passing relatively long time.

Demonstration photos

Figure 9a-e shows the attracting and trapping of reptiles (geckos) and rodents (mice) utilizing the (PVBA/O-10/90)/SBR-98/2–30 wet adhesive. This sample of wet adhesive was chosen is due to the best value of adhesion force among samples (~690 kPa). Figure 9a, b exposes the photos of reptiles (geckos) and Fig. 9c-e shows the photos of rodents (mice). Further, it is observed that the wet adhesive has ability to trap of the individual or groups either reptiles (geckos) or rodents (mice). This is due to the strength of adhesively of (PVBA/O-10/90)/SBR-98/2–30. From authors’ observations during the trapping process of reptiles or rodents are no ability of these creatures to escape, however fierce and lethal resistance from these creatures to run a way. Therefore, it can be said it is possible to produce this adhesive type in mass production and utilizes it in this application.
Conclusion

Wet adhesives are synthesized from poly (vinyl butyral-co-vinyl alcohol-co-vinyl acetate) (PVBA), castor oil (O), and styrene butadiene rubber (SBR) mixture utilizing a wide scale of gamma rays from 0 to 50 kGy with dose rate of ~0.9 kGy/h. The wet adhesives of (PVBA/O) consist of three compositions, 5/95, 10/90 and 15/85 (g/g). The results of preparation for compositions of (PVBA/O) wet adhesives were modified to enhance the wet adhesives properties.
Therefore, SBR was added to (PVBA/O-10/90) mixture to improve the adhesion force. The following wet adhesives of (PVBA/O-10/90)/SBR are formed from three ratios of 99/1, 98/2 and 97/3 (g/g). These wet adhesives are exposed to irradiation dose from 0 to 50 kGy of irradiation dose rate of ~0.9 kGy/h. The synthesized wet adhesives characterized by diverse devices such mechanical test (adhesion force), Fourier transform infrared (FTIR), thermogravimetric analysis and derivative thermal gravimetric (TGA-DTG), gel permeation chromatography (GPC), proton nuclear magnetic resonance spectroscopy (1H NMR) and scan electron microscopy (SEM). The results declared that the optimum sample of wet adhesive and exposure irradiation dose are (PVBA/O-10/90)/SBR-98/2 and 30 kGy, respectively. This poured wet adhesive onto cardboard paper was utilized to trap the reptiles (geckos) and rodents (mice). The results showed that the wet adhesive has an excellent efficiency to trap the reptiles and rodents as well. It is important to mention all rodents and reptiles are alive and free after experiment, therefore SBR was added to (PVBA/O-10/90) mixture to produce a gel–sol transition and shear-thinning features.

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Declarations

Competing interest The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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