



Original Research Article

Pomegranate peel extract inhibits internalization and replication of the influenza virus: An *in vitro* study

Mohammad-Taghi Moradi¹, Ali Karimi^{2,*}, Mahmoud Rafieian-kopaei¹, Mohammad Rabiei-Faradonbeh³, Hassan Momtaz⁴

¹Medical Plants Research Center, Basic Health Sciences Institute, Shahrekord University of Medical Sciences, Shahrekord, Iran

²Cellular and Molecular Research Center, Basic Health Sciences Institute, Shahrekord University of Medical Sciences, Shahrekord, Iran

³Department of Pathobiology, Infectious Disease and Public Health, School of Animal and Veterinary Sciences, University of Adelaide, Adelaide, Australia

⁴Department of Microbiology, College of Veterinary Medicine, Shahrekord Branch, Islamic Azad University

Article history:

Received: Jul 07, 2018

Received in revised form:
Jun 26, 2019

Accepted: Jul 02, 2019

Vol. 10, No. 2, Mar-Apr 2020,
143-151.

* Corresponding Author:

Tel: +983833346692

Fax: +989133013250

kakarimi42@gmail.com

Keywords:

Anti-influenza virus

Pomegranate

Punica granatum L.

Mechanisms

Abstract

Objective: Influenza virus, which is associated with high level of morbidity and mortality, has been recently considered a public health concern; however, the methods of choice to control and treat it are limited. Our previous study showed anti-influenza virus activity of pomegranate peel extract (PPE). In this study, the mechanism through which PPE acts against influenza virus A/Puerto Rico/8/34 (H1N1; PR8) was investigated.

Materials and Methods: Ethyl alcohol extract of pomegranate (*Punica granatum* L.) peel was prepared, and the action mechanism of PPE in inhibiting influenza replication was studied by time-of-drug-addition assay, virucidal activity, RNA replication, hemagglutination inhibition assay, viral mRNA expression, and western blot analysis.

Results: PPE inhibited viral polymerase activity, viral RNA replication, and viral protein expression but could not affect hemagglutination inhibition and virucidal activity. According to time-of-drug-addition assay results, PPE inhibited the virus adsorption and early steps of influenza replication.

Conclusion: This study demonstrated that the antiviral effect of PPE on influenza virus is most probably associated with inhibition of viral adsorption and viral RNA transcription.

Please cite this paper as:

Moradi MT, Karimi A, Rafieian-kopaei M, Rabiei-Faradonbeh M, Momtaz H. Pomegranate peel extract inhibits internalization and replication of the influenza virus: An *in vitro* study. *Avicenna J Phytomed*, 2020; 10(2): 143-151.

Introduction

As an emerging public health issue, influenza virus is one of the most prevalent causes of respiratory tract infection that leads to high morbidity and mortality rates in humans. Annual vaccination is the main

approach to prevent influenza infection. Anti-influenza drugs are also useful to prevent and treat the infection (Hayden, 2006). Currently, there are three groups of anti-influenza agents to fight influenza infection: 1- Amantadine and rimantadine

are matrix protein (M2) ion-channel inhibitors that interfere with intracellular viral uncoating in the host. These are effective only against influenza virus A but have widely acquired resistance to it; 2-neuraminidase (NA) inhibitors such as oseltamivir and zanamivir are widely used to treat seasonal and pandemic influenza virus infections (Jackson *et al.*, 2011); and 3-cap-dependent endonuclease inhibitor such as baloxavir marboxil (CDC, 2018). However, oseltamivir-resistant H1N1 strains have spread since 2007–2008 (Dapat *et al.*, 2013; Van Der Vries *et al.*, 2013). Because of the constant risk of the emergence of antiviral-resistant influenza strains, it is important to consistently seek out drugs that could be used to prevent and treat influenza. As there are few approaches to control and treat this infection, plant extracts including pomegranate peel extract (PPE) can be a treatment of choice.

Pomegranate (*Punica granatum* L., from family *Punicaceae*) is one of the oldest edible fruits that is cultivated in many countries (Elyatem Kader, 1984). It is extensively cultivated in Iran, Egypt, Russia, Spain, France, China, Japan, Argentina, USA, and India. Pomegranate is extensively used in the folk medicine of Iran and many other countries. Many studies have indicated the therapeutic efficacy of pomegranate against different types of disorders (Ibrahium, 2010; Haber *et al.*, 2011; Ismail *et al.*, 2012; Colombo *et al.*, 2013; Asmaa *et al.*, 2015).

Although pomegranate peel is sometimes considered an agro-waste, it is indeed a source of different flavonoids such as kaempferol, kaempferol-3-O-glucoside, epicatechin, catechin, epigallocatechin-3-gallate, flavan-3-ol, kaempferol-3-O-rhamnoglucoside, luteolin 7-O-glucoside, luteolin, naringin, pelargonidin, prodelfhindin, quercetin, and rutin with reported antiviral, antibacterial, anti-inflammatory, antioxidant, and antineoplastic bioactivities (Plumb *et al.*, 2002; Lansky Newman, 2007). Our previous study showed that PPE had interesting

antiviral activity against Influenza virus in MDCK cells (Moradi *et al.*, 2017). The aim of this study was to investigate the action mechanism of PPE against Influenza A/PR/8 virus in MDCK cells.

Materials and Methods

Plant collection and extraction

The pomegranate (*Punica granatum* L.) used in this study was from the *Malas* variety obtained from Shahreza, a central region of Iran. The peel powder was dissolved in 80% ethanol and kept at room temperature for 96 hr. Next, the mixture was filtered and concentrated under nearly vacuum pressure at 40°C in a rotary evaporator.

Cell culture and influenza virus propagation

Influenza virus A/Puerto Rico/8/34 (H1N1; PR8) and Madin Darby Canine Kidney (MDCK) cell line were provided from the Influenza Unit of Pasteur Institute of Iran. MDCK cells were grown in Dulbecco's Modified Eagle's Medium (DMEM, Gibco, USA) with 10% fetal bovine serum (FBS, Gibco, USA), 100 U/ml penicillin, and 10 µg/ml streptomycin (Pen/Strep, Gibco, USA) at 37°C in a humidified incubator with 5% CO₂.

Virus titration

A standard 50% tissue culture infectious dose (TCID₅₀) method was applied for virus titration (Kim *et al.*, 2010). At 90% confluence, MDCK cells were prepared in 96-well plates, the cell culture medium was aspirated and washed twice with phosphate-buffered saline (PBS). Then, 200 µl of 10-fold dilutions of virus in DMEM with 0.5 µg/ml trypsin TPCK was added into the wells and incubated for 2 days. Afterwards, 50 µl of culture medium was taken from each well and transferred to a U-bottomed 96-well plate for hemagglutination assay (WHO, 2011). TCID₅₀ was calculated by the method of Reed and Muench (Reed and Muench, 1938).

Mechanism of action of pomegranate against influenza virus

Cytotoxicity assay

The effect of PPE on the viability of MDCK cells was determined using 3-(4, 5-dimethylthiazol-2-yl)-2, 5-diphenyltetrazoliumbromide (MTT, Sigma, USA) assay according to a previously described method (Mosmann, 1983) with some modifications. Briefly, when the cell monolayer was confluent, the cells were incubated with 200 μ l/well of various concentrations of the extract in 96-well plates for 48 hr. Then, cell monolayers were incubated with 50 μ l of 1 mg/ml MTT in PBS at 37°C for 4 hr and treated with 100 μ l of acidic isopropanol (0.05 N HCl in absolute isopropanol). Afterwards, the plates were shaken for 15 min, the absorbance was read using a reference filter at 640 nm wavelength using a microplate reader (StataFax2100, USA).

Time-of-drug-addition assay

To determine the stage of the viral life cycle that is affected by the PPE, MDCK cells were seeded into 24-well plates and incubated overnight until 90% confluence was achieved. Next, the cells were incubated with 10^4 TCID₅₀ of the virus for 1 hr at 37°C, and washed with PBS, and then fresh medium containing TPCK and maximum non-toxic concentration (30 μ g/ml) of PPE was added. The PPE was added before the adsorption of the virus (-2 to -1 hr), at adsorption (-1 to 0 hr) and at three time points post adsorption (0-2, 2-4, and 4-8 hr). After 8 hr incubation, supernatants were taken and virus progeny yield was determined using TCID₅₀ assay (Matusевич et al., 2015; Zarubaev et al., 2015). In brief, when 90% confluence was achieved, MDCK cells were prepared in 96-well plates, the cell culture medium was aspirated and washed two times with PBS; then, 100 μ l of a series of 10-fold dilutions was added to the wells and left to incubate for 2 days. After 48-hr incubation, virus replication was investigated by hemagglutination assay (Kim et al., 2010; Organization, 2011; Matusевич et al., 2015). TCID₅₀ (log₁₀) was calculated by

the method of Reed and Muench (Reed and Muench, 1938).

Virucidal activity

Maximum non-toxic dilution (30 μ g/ml) of PPE and PBS was incubated with 10^4 TCID₅₀ of the virus for 1 hr at room temperature. Then, the infectious titer of the virus was determined using TCID₅₀ assay (Matusевич et al., 2015).

Inhibition of viral mRNA expression and viral RNA synthesis

Confluent MDCK cells were infected with the virus and treated with different concentrations (30, 10, and 3 μ g/ml) of the extract in 12-well plates for 13 hr (He et al., 2011). Total RNA was extracted from the MDCK cells that were inoculated with either untreated or treated viruses by Trizol (Invitrogen, Waltham, MA, USA) based on the manufacturer's instructions. The extracted RNA was transcribed into cDNA using RevertAid First Strand cDNA synthesis kit (Thermo Scientific, Lithuania) including an influenza A viral RNA-specific universal primer from Uni12 primers (5'-AGCAAAAGCAGG-3') to detect viral RNA (vRNA) or oligo-dT primers to detect viral mRNA (vmRNA), RNase inhibitor, 5X Reaction buffer, and dNTP Mix to a final volume of 20 μ l. Real-time PCR was conducted to detect the vRNA and vmRNA. The vmRNA and vRNA levels were quantified by a RotorGene Q (Corbett, Qiagen, Germany) containing 1 μ l of synthesized cDNA solution, 5 μ l of 2X SYBER Green Master Mix (Thermo scientific, Lithuania), and 500 nM of each primer (Table 1) to a final volume of 10 μ l. Amplification protocol consisted of denaturation at 95°C for 10 min followed by 45 cycles at 95°C for 15 sec, 72°C for 25 sec and, and 54 or 58°C for 20 sec. Next, the specificity of the amplified products was confirmed with reference to melting curve analysis. All the reactions were performed in two independent repeats in duplicate.

Table 1. Primers used in real-time RT-PCR.

Gene name	Primer sequence	Melt temperature (°C)	Product length (bp)
<i>Nucleocapsid protein (NP)</i>	F:TGTGTATGGACCTGCCGTAGC	62.1	158
	R:CCATCCACACCAAGTTGACTCTTG	61.3	
<i>Hemagglutinin (HA)</i>	F:CCTGCTCGAAGACAGCCACAACG	60.6	98
	R:TTCCCAAGAGCCATCCGGCGA	58.3	
<i>Nonstructural protein (NSI)</i>	F:CATAATGGATCCAAACACTGTGTC	58.1	138
	R:CCTCTTAGGGATTCTGATCTCGG	60	
<i>Matrix protein (M)</i>	F:GGCAAATGGTACAGGCAATG	57.7	144
	R:AGCAACGAGAGGATCACTTG	57.6	
<i>GAPDH</i>	F:GGAGAAAGCTGCCAAATATGACGA	61.4	140
	R:CGAAGGTGGAAGAGTGGGTGT	61.9	

GAPDH: *Canis lupus familiaris* glyceraldehyde-3-phosphate dehydrogenase

A mixture without cDNA template was used as negative control. The expression of mRNA was normalized against that of the control housekeeping gene (*GAPDH*) and the relative changes in gene expression were calculated using the relative quantitative method ($2^{-\Delta\Delta C_t}$). The effects on viral RNA synthesis were calculated by absolute quantification and represented as log₁₀ copy number decrements in treatments.

Construction of the plasmid standards for quantification

For quantification of real-time PCR assay, the amplified M2 gene was T/A cloned in pTZ57R/T vector (Invitrogen, San Diego, CA). Vectors were transformed into *Escherichia coli* TOP10F' competent cells using calcium chloride solution and under heat shock (42°C) for 90 sec. To screen recombinant vectors, competent cells were cultured in Luria broth (LB) agar (Merck Co., Germany) containing IPTG (0.1 M), ampicillin (100 µg/ml), and Xgal (20 mg/ml) at 37°C overnight. The white colonies were selected and cultured again in LB agar (containing ampicillin) at 37°C overnight. The recombinant vectors were extracted from bacterial cells by Plasmid Mini Extraction Kit (Bioneer, South Korea) according to the manufacturer's instructions and PCR was conducted to confirm cloning. The concentrations of extracted plasmids were measured spectrophotometrically using a Nanodrop system (Implen Nano Photometer™, Germany). The plasmid copy number was calculated according to the size of the original plasmid alongside the cloned

inserts and the concentration of the construct was calculated by the following formula:

$$\text{Number of copies}/\mu\text{l} = (6.02 \times 10^{23} \text{copies} \times \text{plasmid concentrations (g}/\mu\text{l)}) / (\text{Number of bases pairs} \times 660 \text{ daltons/base})$$
 (Godornes et al., 2007).

To plot standard curves, ten-fold serial dilutions of the plasmid were prepared and the M2 gene in plasmids was amplified in triplicate for each standard dilution point. Real time RT-PCR quantification was done and the expression of the gene was measured.

Hemagglutination inhibition (HI) assay

The HI assay was used to investigate the effect of the extract on influenza virus hemagglutinin (Abdal Dayem et al., 2015). Briefly, 50 µl of two-fold serial dilutions of the extract were diluted in PBS containing 0.1% BSA mixed with 50 µl of the virus in PBS containing 0.1% BSA. After 1 hr of incubation, the HI assay was carried out to measure virus titration. Titers were expressed as HA units/50 µl (HAU/50 µl) in comparison with the control treatment (virus without extract).

Western blot analysis

MDCK cells in 6-well plates were inoculated with PR8 at 100 TCID₅₀ in the presence of crude extract (30 and 15 µg/ml) for 24 hr at 37°C. The culture medium was removed and cells were washed twice with cold PBS and lysed in ice-cold radioimmunoprecipitation assay buffer (6X) containing a protease inhibitor cocktail. Protein concentration was measured by Bradford assay (BioRad), and

Mechanism of action of pomegranate against influenza virus

equal amounts of protein from each sample underwent blotting.

The protein lysates were mixed with SDS loading buffer (0.125 M Tris-HCl 4%, SDS 20%, glycine 10%, and 2-mercaptoethanol), boiled for 5 min, separated by 12% sodium dodecyl sulfate polyacrylamide gel electrophoresis (SDS-PAGE) and transferred to polyvinylidene difluoride (PVDF; Bio-Rad, USA) membrane using semi-dry transfer system (Bio-Rad, USA). Viral nucleoprotein (NP), M1 protein, and cellular β -actin protein (loading control) were detected using anti-NP (Thermo Fisher Scientific, USA), anti-M1 (Thermo Fisher Scientific, USA) and β -actin antibodies (Abcam; USA), respectively. The horseradish peroxidase conjugated secondary antibodies (goat anti-rabbit/IgG) were used and the bound antibodies were detected using C-DiGit® Blot Scanner (LI-COR, USA).

Statistical analysis

Data analysis was conducted by SPSS software (Ver. 16). Kruskal-Wallis test was used to investigate intergroup differences. A p value < 0.05 was considered statistically significant.

Results

PPE affects an early stage of virus infection

To determine the stage of viral cycle where the extract exhibited its activity, time-of-drug-addition assays were performed on one cycle of influenza virus replication. The measurements of virus titer showed that virus titer decreased most markedly when the compound was present in the system during the whole test. In addition, the virus titer decreased significantly at time points (-1 hr) to 0 and 0 to 2 hr (Figure 1).

PPE inhibits viral protein synthesis

The levels of influenza viral mRNA in the crude extract-treated and untreated infected cells were compared. RNA

extraction was conducted at 13 hr after infection with influenza virus, and then the measurements of the intracellular influenza vRNA (NS1, NP, HA and M2 genes) levels were performed. Quantitative real-time PCR showed a significant and dose dependent decrease of influenza mRNA expression level in the crude extract-treated cells compared with untreated virus infected cells ($p < 0.05$; Figure 2).

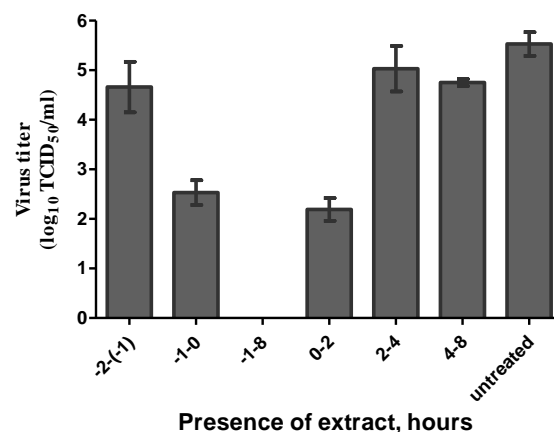


Figure 1. Time-of-addition activity of pomegranate peel extract on influenza virus. Influenza A virus was adsorbed to MDCK cells (10^4 TCID₅₀) for 1 hr. After washing non-absorbed virus, the crude extract was added at its maximum nontoxic concentration (30 μ g/ml) to the cell-virus system at the following time points: -2 to -1 hr (before the adsorption of the virus), and -1 to 0 hr (adsorption) as well as at several time points post adsorption: 0–2, 2–4, and 4–8 hr. Virus titer was determined after 8 hr of incubation in MDCK cells using TCID₅₀ assay.

To investigate viral protein synthesis in the cells after the inoculations of the virus, viral NP and M1 were studied using western blotting. We found that PPE inhibited the viral protein synthesis in a dose-dependent manner (Figure 3). Results indicated that the PPE inhibited the viral protein synthesis.

PPE inhibits viral RNA replication

The synthesis of viral RNA in the cells treated with different concentrations of PPE and untreated cells was compared 13 hr after the inoculation of the virus. The effects of the extract on the levels of viral RNA load were calculated using absolute quantification and shown as log₁₀ copy number decrements in treatments.

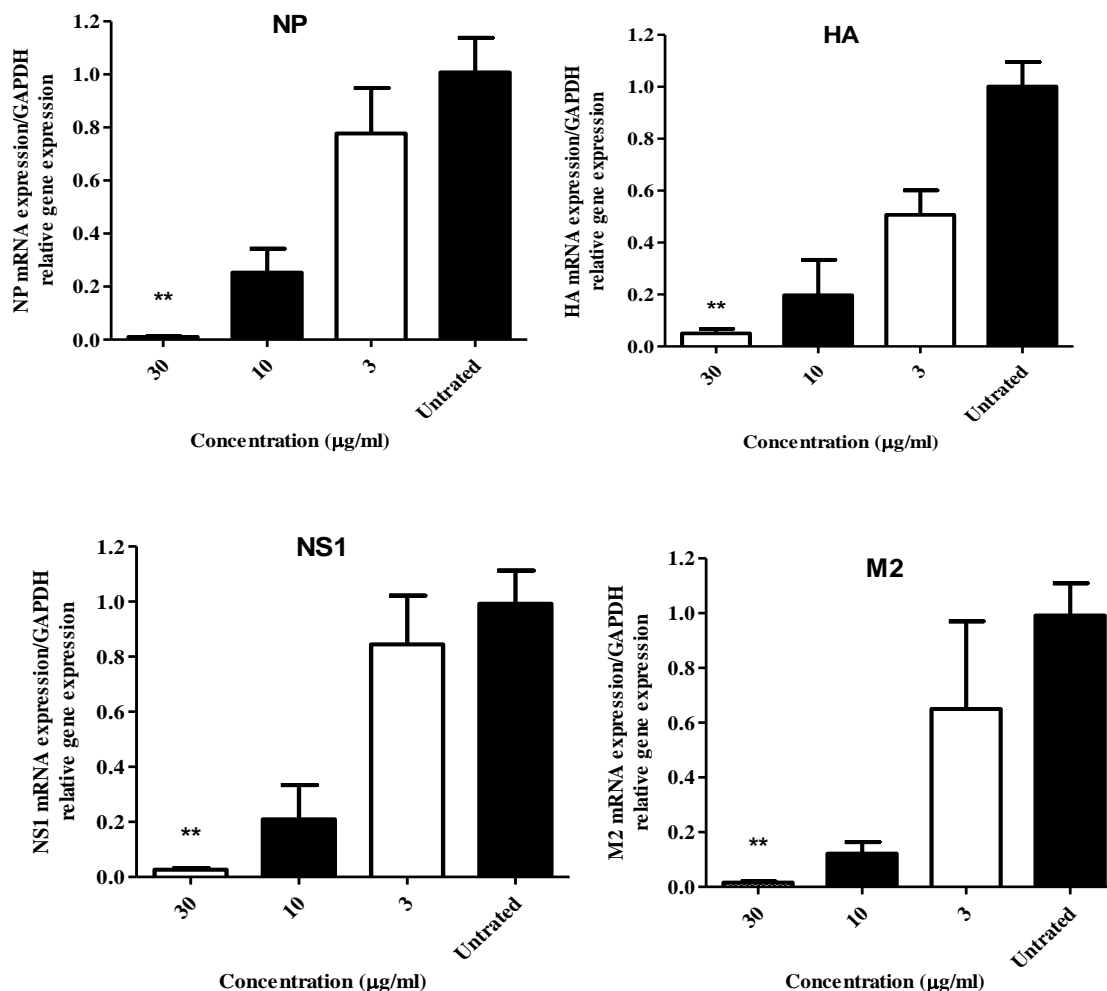


Figure 2. Effects of pomegranate peel extract on the expression of viral mRNA in MDCK cells. Cells were infected with Influenza A virus and treated with different concentrations (30, 10, and 3 µg/ml) of the extract. Total RNA was extracted 13 hr after influenza virus infection and the intracellular levels of mRNA influenza genes (NS1, NP, M1, and HA) were measured. Influenza virus mRNA levels were normalized by *GAPDH*. The data are the mean values of 2 independent repeats in duplicate (mean±SD). **p<0.01 comparison with the virus untreated sample using Kruskal Wallis test.

The quantitative analysis of influenza virus M2 gene revealed statistically significant and dose-dependent decrements in viral load when compared to the virus sample (Table 2).

PPE does not have virucidal activity

To investigate the antiviral action mechanism of the extract, a series of tests were conducted to examine its virucidal property and cellular localization. Results showed that virus yield in the extract and control groups was 4.9 ± 0.56 and 5.08 ± 0.59 (log₁₀-TCID₅₀), respectively (p>0.05). This confirmed that the extract did not exert any virucidal effect.

Table 2. Effects of PPE on the viral RNA copy number.

Samples	Ct (Mean±SD)	Log ₁₀ Copy Numbers (Mean±SD)
Virus control (untreated)	19.97±0.283	4.09±0.071
Pomegranate peel treated	30 (µg/ml)	30.05±0.947
	10 (µg/ml)	25.24±0.092
	3 (µg/ml)	22.66±0.0058

Cells were infected with Influenza A virus and treated with different concentrations of pomegranate peel extract. Total RNA was extracted 13h after influenza virus infection and the Log₁₀ copy numbers relating to Ct values of intracellular influenza M gene were measured. Data are averages of 2 independent repeats in duplicate. *significant decrease in comparison with the virus untreated sample (p< 0.05).

Mechanism of action of pomegranate against influenza virus

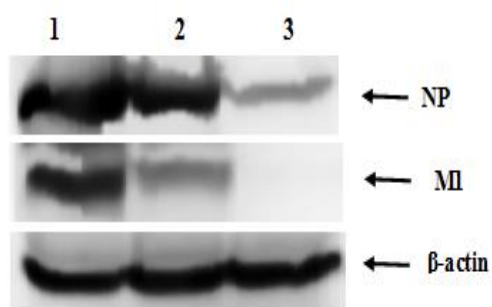


Figure 3. Effects of pomegranate peel extract on protein synthesis in MDCK cells. MDCK cells were infected with Influenza A virus and then incubated with different concentrations (15 and 30 $\mu\text{g/ml}$) of the extract for 24 hr at 37°C. The viral proteins, NP and M1, were detected using their specific primary antibodies and HRP-conjugated secondary antibodies. Cellular β -actin was used as a loading control. Well 1: virus control, well 2: virus + 15 $\mu\text{g/ml}$ crude extract, and well 3: virus + 30 $\mu\text{g/ml}$ crude extract.

PPE does not block the hemagglutination activity

HI assay was used to determine whether PPE could prevent virus particles binding to cell surface receptors. The HI assay results indicated that pretreatment with the crude extract could not prevent the binding of this virus to RBCs (data not shown).

Discussion

P. granatum is a frequently used and important herb in folk medicine and its antibacterial, antiparasitic, apoptotic, antifungal, antiproliferative, and antiviral activities have been studied (Kim et al., 2002; Reddy et al., 2007; Howell D'souza, 2013). Few studies have reported the inhibitory effects of *P. granatum* fruit on herpes virus, influenza virus, poxviruses, and human immunodeficiency virus (Haidari et al., 2009; Howell D'souza, 2013).

In this study, the action mechanism of PPE was investigated against influenza A/PR/8 virus in MDCK cells. The results of time-of-drug-addition assay regarding one cycle of influenza virus replication showed that the greatest virus inhibition by PPE was seen at (-1) to 0 hr and 0 to 2 hr after infection. This finding may suggest that

PPE inhibits the early step of influenza replication and virus adsorption but does not interfere with the virus binding to the receptors. Besides, our HI assay results indicated that PPE did not inhibit virus-induced hemagglutination. In addition, PPE decreased influenza virus adsorption without influencing HA-mediated virus adsorption. Thus, two possible explanations for the impaired adsorption of influenza virus are; 1) PPE-mediated inactivation of the influenza virus neuraminidase (NA) protein, which cleaves sialic acid in the cell surface and promotes virus internalization (Ohuchi et al., 2006) and 2) PPE's ability to induce physical damage to the virus particles, probably the lipid bilayers, which can lead to the loss of their hemifusion capacity. Anti-adsorption effects of this extract deserve further research.

We clearly observed the ability of this extract in reducing the viral polymerase activity and RNA level. Time-of-drug-addition assays also demonstrated that PPE inhibited influenza replication in the early step. It has been reported that before 2.5 hr, the NP and NS1 proteins are preferentially synthesized (Kummer et al., 2014). The expression of the NP becomes visible 2-4 hr after infection with strong nuclear accumulation (Shapiro et al., 1987). In influenza virus, the genomic RNAs (vRNAs) are associated with several copies of NPs and a few number of RNA-dependent RNA polymerase complexes consisting of PA, PB1, and PB2, which integrate into ribonucleoprotein complex (RNP) that is necessary for the replication and transcription of the viral RNAs (Sugita et al., 2013). According to the current study, PPE may decrease the NP level and viral polymerase activity and consequently affect the activities of RNP complexes, leading to inhibition of both transcription and replication of the RNA level. Additional studies, however, should be conducted to identify the precise target of the extract throughout the influenza virus life cycle.

This study demonstrated that *in vitro* antiviral effect of PPE on influenza virus is most probably associated with inhibition of viral adsorption and viral RNA transcription. This extract should be also studied in clinical trials so that it can ultimately be used as a herbal drug against the influenza virus.

Acknowledgment

We thank Dr. Fatemeh Fotouhi (Pasteur Institute of Iran, Tehran, Iran) for kindly providing the virus. This work was supported by Shahrekord University of Medical Science, Shahrekord, Iran (Grant No. 2489). Authors also gratefully thank the Director of Medical Plants Research Center and the Deputy of Research and Technology of Shahrekord University of Medical Sciences, Shahrekord, Iran.

Conflicts of interest

The authors have declared that there is no conflict of interest.

References

- Abdal Dayem A, Choi HY, Kim YB, Cho SG. 2015. Antiviral effect of methylated flavonol isorhamnetin against influenza. *PLoS One*, 10: e0121610.
- Asmaa MJ, Ali AJ, Farid JM, Azman S. 2015. Growth inhibitory effects of crude pomegranate peel extract on chronic myeloid leukemia, K562 cells. *J Appl Basic Med Res*, 5: 100-105.
- Centers for Disease Control and Prevention. 2018. Influenza antiviral medications: summary for clinicians. Available on: <https://www.cdc.gov/flu/professionals/antivirals/summary-clinicians.htm> (Accessed on December 10, 2018).
- Colombo E, Sangiovanni E, Dell'agli M. 2013. A review on the anti-inflammatory activity of pomegranate in the gastrointestinal tract. *Evid Based Complement Alternat Med*, 2013: 247145.
- Dapat C, Kondo H, Dapat IC, Baranovich T, Suzuki Y, Shobugawa Y, Saito K, Saito R, Suzuki H. 2013. Neuraminidase inhibitor susceptibility profile of pandemic and seasonal influenza viruses during the 2009-2010 and 2010-2011 influenza seasons in Japan. *Antiviral Res*, 99: 261-269.
- Elyatem SM, Kader AA. 1984. Post-harvest physiology and storage behaviour of pomegranate fruits. *Sci Hortic*, 24: 287-298.
- Godornes C, Leader BT, Molini BJ, Centurion-Lara A, Lukehart SA. 2007. Quantitation of Rabbit Cytokine mRNA by Real-Time RT-PCR. *Cytokine*, 38: 1-7.
- Haber SL, Joy JK, Largent R. 2011. Antioxidant and antiatherogenic effects of pomegranate. *Am J Health Syst Pharm*, 68: 1302-1305.
- Haidari M, Ali M, Ward Casscells S, Madjid M. 2009. Pomegranate (*Punica granatum*) purified polyphenol extract inhibits influenza virus and has a synergistic effect with oseltamivir. *Phytomedicine*, 16: 1127-1136.
- Hayden FG. 2006. Respiratory viral threats. *Curr Opin Infect Dis*, 19: 169-178.
- He W, Han H, Wang W, Gao B. 2011. Anti-influenza virus effect of aqueous extracts from dandelion. *Virology J*, 8: 538-538.
- Howell AB, D'Souza DH. 2013. The Pomegranate: effects on bacteria and viruses that influence human health. *Evid Based Complement Alternat Med*, 2013: 606212.
- Ibrahium M. 2010. Efficiency of pomegranate peel extract as antimicrobial, antioxidant and protective agents. *World J Agric Sci*, 6: 338-344.
- Ismail T, Sestili P, Akhtar S. 2012. Pomegranate peel and fruit extracts: a review of potential anti-inflammatory and anti-infective effects. *J Ethnopharmacol*, 143: 397-405.
- Jackson RJ, Cooper KL, Tappenden P, Rees A, Simpson EL, Read RC, Nicholson KG. 2011. Oseltamivir, zanamivir and amantadine in the prevention of influenza: a systematic review. *J Infect*, 62: 14-25.
- Kim ND, Mehta R, Yu W, Neeman I, Livney T, Amichay A, Poirier D, Nicholls P, Kirby A, Jiang W, Mansel R, Ramachandran C, Rabi T, Kaplan B, Lansky E. 2002. Chemopreventive and adjuvant therapeutic potential of pomegranate (*Punica granatum*) for human breast cancer. *Breast Cancer Res Treat*, 71: 203-217.
- Kim Y, Narayanan S, Chang KO. 2010. Inhibition of influenza virus replication by plant-derived isoquercetin. *Antiviral Res*, 88: 227-235.
- Kummer S, Flöttmann M, Schwanhäusser B,

Mechanism of action of pomegranate against influenza virus

- Sieben C, Veit M, Selbach M, Klipp E, Herrmann A. 2014. Alteration of protein levels during influenza virus H1N1 infection in host cells: a proteomic survey of host and virus reveals differential dynamics. *PLoS One*, 9: e94257.
- Lansky EP, Newman RA. 2007. *Punica granatum* (pomegranate) and its potential for prevention and treatment of inflammation and cancer. *J Ethnopharmacol*, 109: 177-206.
- Matusevich OV, Egorov VV, Gluzdikov IA, Titov MI, Zarubaev VV, Shtro AA, Slita AV, Dukov MI, Shurygina AP, Smirnova TD, Kudryavtsev IV, Vasin AV, Kiselev OI. 2015. Synthesis and antiviral activity of PB1 component of the influenza A RNA polymerase peptide fragments. *Antiviral Res*, 113: 4-10.
- Moradi MT, Karimi A, Lorigooini Z, Pourgheysar B, Alidadi S, Hashemi L. 2017. In vitro anti influenza virus activity, antioxidant potential and total phenolic content of twelve Iranian medicinal plants. *Marmara Pharm J*, 21: 843-851.
- Mosmann T. 1983. Rapid colorimetric assay for cellular growth and survival: application to proliferation and cytotoxicity assays. *J Immunol Methods*, 65: 55-63.
- Ohuchi M, Asaoka N, Sakai T, Ohuchi R. 2006. Roles of neuraminidase in the initial stage of influenza virus infection. *Microbes Infect*, 8: 1287-1293.
- Plumb GW, de Pascual-Teresa S, Santos-Buelga C, Rivas-Gonzalo JC, Williamson G. 2002. Antioxidant properties of gallicocatechin and prodelphinidins from pomegranate peel. *Redox Report*, 7: 41-46.
- Reddy MK, Gupta SK, Jacob MR, Khan SI, Ferreira D. 2007. Antioxidant, antimalarial and antimicrobial activities of tannin-rich fractions, ellagitannins and phenolic acids from *Punica granatum* L. *Planta Med*, 73: 461-467.
- Reed LJ, Muench H. 1938. A simple method of estimating fifty per cent endpoints. *Am J Epidemiol*, 27: 493-497.
- Shapiro GI, Gurney T, Jr Krug RM. 1987. Influenza virus gene expression: control mechanisms at early and late times of infection and nuclear-cytoplasmic transport of virus-specific RNAs. *J Virol*, 61: 764-773.
- Sugita Y, Sagara H, Noda T, Kawaoka Y. 2013. Configuration of Viral Ribonucleoprotein complexes within the influenza A virion. *J Virol*, 87: 12879-12884.
- van der Vries E, Schutten M, Fraaij P, Boucher C, Osterhaus A. 2013. Influenza virus resistance to antiviral therapy. *Adv Pharmacol*, 67: 217-246.
- World Health Organization (WHO). 2011. Global Influenza Surveillance Network. Manual for the laboratory diagnosis and virological surveillance of influenza. Available from: http://whqlibdoc.who.int/publications/2011/9789241548090_eng.pdf (Last access: 06/25/2014).
- Zarubaev VV, Garshina AV, Tretiak TS, Fedorova VA, Shtro AA, Sokolova AS, Yarovaya OI, Salakhutdinov NF. 2015. Broad range of inhibiting action of novel camphor-based compound with anti-hemagglutinin activity against influenza viruses in vitro and in vivo. *Antiviral Res*, 120: 126-133.