J. Dairy Sci. 102:3879–3886
https://doi.org/10.3168/jds.2018-16019

Characterization and adsorption of a *Lactobacillus plantarum* virulent phage

X. Chen,[1] J. Guo, Y. Liu, S. Chai, R. Ma, and B. Munguntsetseg
Key Laboratory of Dairy Biotechnology and Engineering, Ministry of Education, Key Laboratory of Dairy Products Processing, Ministry of Agriculture, Inner Mongolia Agricultural University, Hohhot, 010018, P.R. China

ABSTRACT

Bacteriophage infection of lactic acid bacteria is considered one of the biggest worldwide problems in the food industry. Bacteriophages may cause negative effects on the fermentation of various dairy-based products. A virulent bacteriophage was isolated from an abnormal fermentation liquid of *Lactobacillus plantarum* IMAU10120. The characterization and influence of temperature, pH, divalent cations, and chloramphenicol on the adsorption ability of this phage were evaluated. The results showed that this phage belonged to the *Siphoviridae* family. It exhibited a burst time of 135 min and a burst size of approximately 215 counts expressed per milliliter per infective center. No significant effect was shown to influence its viability and adsorption at 10 to 37°C. More than 90% of phages exhibited infectivity from pH 5 to 9. Divalent ions and chloramphenicol did not have a significant influence on the adsorption of this phage. The information obtained in this study will enrich the database of lactobacilli virulent phages and provide a basis of information for the control of phages in the food fermentation industry.
Key words: *Lactobacillus plantarum* virulent bacteriophage, tolerance, adsorption

INTRODUCTION

Bacteriophages of lactic acid bacteria have gained increasing attention over the past few decades because of their negative effects on the fermentation of various dairy-based products such as yogurt and cheese (Samson and Moineau, 2013). Starter culture failure or slow culture may result in significant economic losses in the dairy industry in terms of both time and starting material while also resulting in a poor-quality product with unacceptable organoleptic properties (Mahony et al., 2017). Phage contamination in fermentation vats has been reported to result from raw processed or recycled ingredients, including whey powder, air, and poorly sanitized process equipment. Today, the dairy industry has designed new protocols to detect and control phages (Garneau and Moineau, 2011).

Lysis of bacteria by phage consists of 5 basic steps: attachment, penetration, replication, virion assembly, and release. Adsorption is a key stage in virus recognition of a sensitive host cell, which can be divided into nonspecific and specific types (Rakhuba et al., 2010). Nonspecific adsorption between a phage and the bacterial surface is reversible, and external conditions such as temperature and pH are influential. Studies concerning the physiological and environmental factors on phage propagation and adsorption have been previously reported (Capra et al., 2006; Briggiler Marcó et al., 2010; Cvirkaitė-Krupovič et al., 2010; Mahony et al., 2015; Chen et al., 2016). In the event that the bacteriophage tail and bacterial surface receptor sites come together due to specific covalent binding, an irreversible adsorption process ensues. This step is a major factor contributing to the specificity of the phage to its host. Researchers have shown that carbohydrates, proteins, or both located in the bacterial cell membrane or cell wall can act as receptor sites that play an important role in the adsorption process (Bebeacua et al., 2013; McCabe et al., 2015). Therefore, alterations in the receptor structures can prevent the adsorption of a particular phage by increasing the host strain's resistance (Munsch-Alatossava and Alatossava, 2013).

Lactobacillus plantarum is used as a starter culture in many fermented milks, vegetables, and meats and is considered a major probiotic (Vries et al., 2006; Giraffa et al., 2010; Ferrando et al., 2015). Similar to other lactic acid bacteria, *L. plantarum* may be attacked by specific phages, resulting in lysis and subsequent slow or substandard fermentation. Recognizing the biological characteristics of related phages can provide a basis for mitigation protocols that could be used in the food industry. To date, information related to *L. plantarum* phages is limited.

Lactobacillus plantarum IMAU 10120 is a starter culture that exhibits several desirable properties, such as

Received November 20, 2018.
Accepted January 19, 2019.
[1]Corresponding author: chenxia8280@163.com

high acid and bile tolerance, good aggregation, antibacterial activities, high soy milk fermentation efficiency, and strong stability upon storage. Chen et al. (2016) isolated a *Lactobacillus* virulent phage (**P1**) from its abnormal fermented liquid and researched its biological properties and the influence of physicochemical parameters on its adsorption. Unfortunately, the abnormal fermentation occurred again, and a new bacteriophage (**P2**) was isolated. The aim of the present study was to evaluate the characteristics and influence of various physicochemical parameters on the viability and adsorption ability of phage P2.

MATERIALS AND METHODS

Bacterial Strains, Phage, and Culture Condition

Phage P2 was initially isolated from the broth culture of a slowly fermenting *L. plantarum* IMAU 10120 (Lactic Acid Bacteria Collection Center in the Key Laboratory of Dairy Biotechnology and Engineering, Ministry of Education, Inner Mongolia Agricultural University, Hohhot, P.R. China). The host strain, *L. plantarum* IMAU10120, was grown at 37°C in de Man, Rogosa and Sharpe (**MRS**) broth (Becton Dickinson, Franklin Lakes, NJ). We used MRS broth supplemented with 10 m*M* $CaCl_2$ (**MRS-Ca** broth) for phage amplification. Phage stocks were prepared as described previously (Neviani et al., 1992) and stored as lysates at 4°C. Phage counts were obtained using a double-layer plaque titration method and expressed in plaque-forming units per milliliter by the methods described by Quiberoni et al. (2011) with some modification. In brief, 100 μL of phage suspension was mixed with host bacteria suspended in a top layer of melted MRS agar (20 mL, 0.7% wt/vol agar) containing 10 m*M* $CaCl_2$ and maintained at 46°C. The top layer was immediately poured into Petri dishes (90 mm) containing a bottom agar of MRS agar (1.5% wt/vol agar). All plates were incubated at 37°C for 16 to 18 h before they were examined for plaques.

Electron Microscopy

Phage electron micrographs were obtained according to De Antoni et al. (2010). Phage suspensions were concentrated by centrifugation (1 h, 70,000 × *g*, 5°C) and stained using either uranyl acetate (2% wt/vol, pH 4.5) or phosphotugstic acid (2% wt/vol). Electron micrographs were taken using a Jeol H-7000 electron microscope (Jeol USA Inc., Peabody, MA) operating at 75 kV. Phage morphology, capsid diameter, and tail length and width were recorded.

1-Step Growth Curve

Lactobacillus plantarum IMAU10120 was grown to the exponential phase (optical density at 600 nm = 0.5) and harvested by centrifugation. The pellet was subsequently resuspended in 100 μL of MRS-Ca broth. Phages were added at a multiplicity of infection (**MOI**) of 2. After adsorption (15 min at 37°C), cells were harvested by centrifugation (10,000 × *g* for 5 min) at room temperature. The resulting pellet was resuspended in MRS-Ca broth and incubated at 37°C. At regular intervals (15 min), 100 μL of each dilution was collected for phage enumeration (Capra et al., 2006). The latent period, burst time, and burst size were calculated from a 1-step growth curve.

Influence of Temperature on Phage Viability

Phages (10^7 pfu/mL) were suspended in MRS broth, placed into Eppendorf tubes (1 mL final volume), and incubated at 0, 10, 20, 30, 37, 42, and 50°C for 30 min. The surviving phages were immediately counted as previously described, and the results were expressed as a percentage of remaining phage counts versus initial phage counts.

Influence of pH on Phage Viability

Phages (10^7 pfu/mL) were suspended in MRS broth at a pH from 2 to 11, placed into Eppendorf tubes (1 mL final volume), and incubated at 37°C for 30 min. The surviving phages were immediately counted as previously described. The results were expressed as a percentage of remaining phage counts versus the initial phage counts.

Influence of Temperature on Phage Adsorption

The influence of temperature on the adsorption of phage was determined at 0, 10, 20, 30, 37, 42, and 50°C. *Lactobacillus plantarum* cultures (MOI = 0.5) were suspended in MRS broth with incubation at 30 min. Plaque formation was investigated using the double-layer plaque technique as previously described. Results are expressed as the percentage of adsorption after 30 min and plotted against temperature values.

Influence of pH on Phage Adsorption

The influence of pH (from 4 to 11) on cell lysis was evaluated by incubating *L. plantarum* (MOI = 0.5) cultures in MRS broth at 37°C for 30 min. Plaque for-

mation was investigated using the double-layer plaque technique as previously described. Results are expressed as a percentage of adsorption after 30 min and plotted against pH values.

Influence of Divalent Cations on Phage Adsorption

The influence of Ca^{2+} and Mg^{2+} on cell lysis was evaluated by incubating *L. plantarum* (MOI = 0.5) in MRS broth with and without $CaCl_2$ or $MgCl_2$ (10 mmol/L) at 37°C. At intervals of 0, 15, and 30 min, tubes were centrifuged (10,000 × *g* for 5 min) and the supernatants were analyzed for unabsorbed phages using a double-layer plate titration method as previously described. Counts were compared with the titer of a control without cells. The results are expressed as a percentage of adsorbed phage to initial phage.

Influence of Cell Protein Synthesis Inhibitors on Phage Adsorption

The minimum concentration of chloramphenicol needed to inhibit protein synthesis in *L. plantarum* IMAU10120 was determined as described by Briggiler Marcó et al. (2010). Host cells were treated with chloramphenicol (20 μg/mL), and the chloramphenicol was removed after the inhibition of protein synthesis was achieved. Treated cells were infected with phage (MOI = 0.5) and then incubated at 37°C for 30 min. After centrifugation (10,000 × *g* for 5 min), the titers of unadsorbed free phages in the supernatants were assayed as indicated, and the results were expressed as percentages of the adsorption. A cell culture subjected to a similar treatment but without chloramphenicol was used as adsorption control.

Statistical Analysis

All data were analyzed using Originpro software (8.6, Originlab, Originlab Corp., Northampton, MA). Experiments were replicated 3 times. Means were compared using the 1-way ANOVA procedure in SPSS (version 20.0.0, IBM Corp., Armonk, NY) at $P < 0.05$.

RESULTS AND DISCUSSION

Electron Microscopy

Phage infection is considered to be one of the most prevalent reasons for starter culture failure in the fermentation production of dairy and meat products, which may cause economic losses for the manufacturers. Research on their characteristics has therefore become important for the development of new phage control strategies. Phage P2 was isolated from the abnormal fermented liquid of *L. plantarum* IMAU 10120. Its electron micrograph is shown in Figure 1. The results showed that this phage had an isometric capsid of approximately 66.7 ± 3.0 nm and a long noncontractile tail (approximately 216.7 ± 3.0 nm long and 12.3 ± 3.0 nm wide). Based on its morphology, it was ascribed to the *Siphoviridae* family, which is frequently associated with lactic acid bacteria phages (Dieterle et al., 2014).

In 2016, phage P1 was isolated from the same host strain with characteristics similar to those belonging to the *Siphoviridae* family. A major difference between phages P1 and P2 was size. Phage P1 was larger, with an isometric capsid of 71.7 ± 3.0 nm and long noncontractile tails (approximately 272 ± 3.0 nm long and 11.3 ± 1.5 nm wide; Chen et al., 2016). Ackermann (2007) also reported that for various *Lactobacillus* phages, almost 60% belonged to the *Siphoviridae* family. Villion and Moineau (2009) reported that of 24 *L. plantarum* phages identified, 19 belonged to the *Siphoviridae* family; the remaining were classified as belonging to the *Myoviridae* family.

1-Step Growth Curve

Figure 2 shows the 1-step growth curve of phage P2. The latent period was 30 min with a burst time of 135 min. The burst size was 214.5 ± 4.0 pfu/infective center. For phage P1, which was isolated from the same host strain, the latent time was 45 min, the burst time was 90 min, and the burst size was 132.88 ± 2.37 pfu/infective center (Chen et al., 2016). Compared with phage P1, phage P2 showed a shorter latent time, longer burst time, and higher burst size.

In 2015, Zhang et al. (2015) isolated a virulent phage (Lcb) of *Lactobacillus casei* ATCC 393 and reported a latent period of approximately 75 min, followed by a relatively short burst period of 45 min; the burst size was approximately 16 pfu/infective center at 30°C. Sunthornthummas et al. (2017) reported a 55-min latent period for *L. paracasei* phage ΦT25 at 37°C, followed by a 55-min rise period and an average burst size of approximately 38 phage particles per infected cell. In 2009, Villion and Moineau (2009) reviewed the characteristics of 8 *L. plantarum* phages and found that only 1 phage, fri, which was isolated from the *L. plantarum* portion of a commercial meat starter culture, expressed a burst size of 200 pfu/infective center. For phage P2, it expressed a short latent period (30 min) at 37°C, followed by 105-min rise period and an average

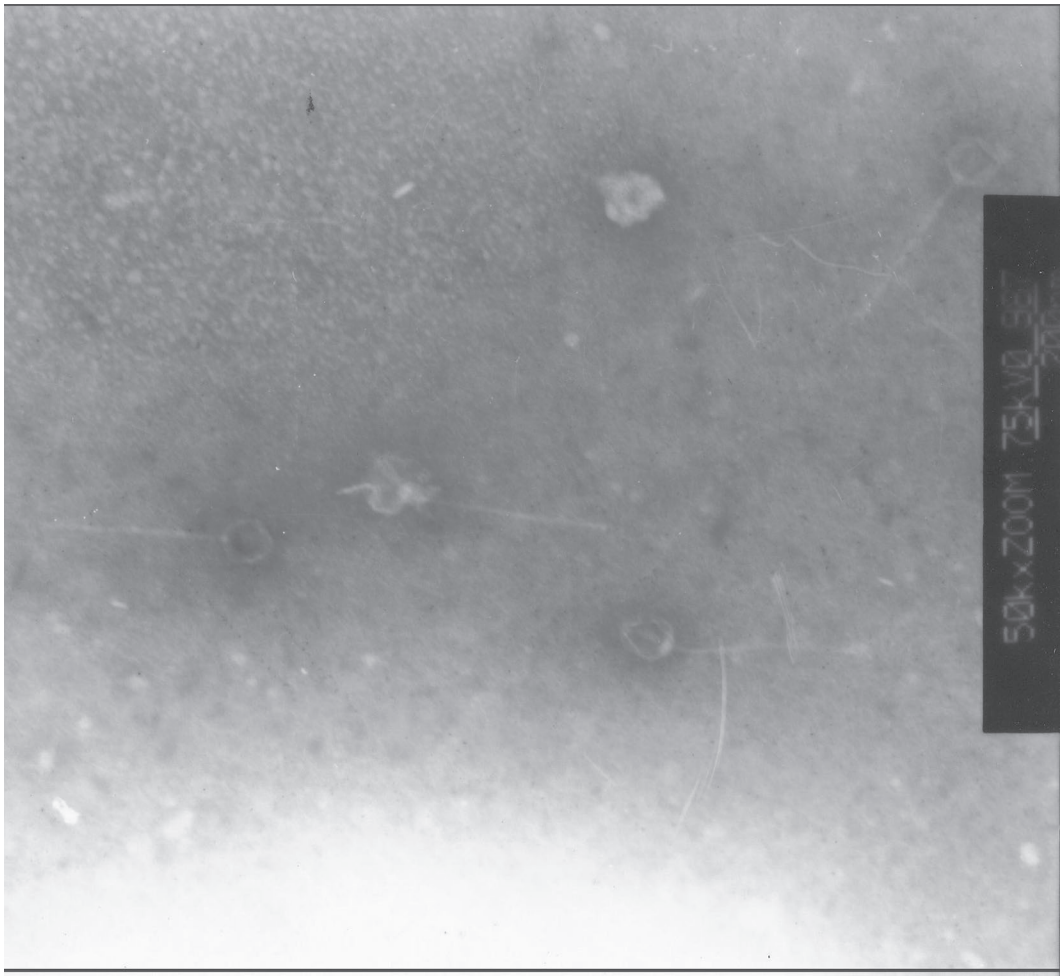

Figure 1. Electron micrograph of *Lactobacillus plantarum* phage P2.

burst size of approximately 214.5 pfu/infective center. If *L. plantarum* phage P2 contaminates fermentation, it might result in severe effects.

Influence of Temperature on Phage Viability

Temperature plays a fundamental role in attachment, penetration, multiplication, and the length of the latent period (Jończyk et al., 2011). Figure 3 shows the influence of temperature on the viability of phage P2. No significant effect ($P < 0.05$) on viability was demonstrated at temperatures of 10 to 37°C. However, when the temperature was reduced to 0°C or increased to 42°C, the survival rate was significantly reduced. The survival rate decreased to approximately 13% following incubation at 50°C for 30 min.

The results obtained in this study indicated that the previous phage, P1, isolated from the same bacterium was more temperature resistant compared with P2

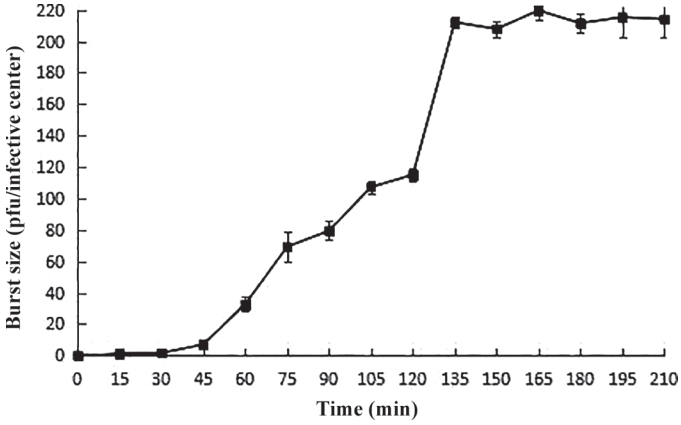

Figure 2. One-step growth curve of *Lactobacillus plantarum* phage P2. Error bars represent 95% CI.

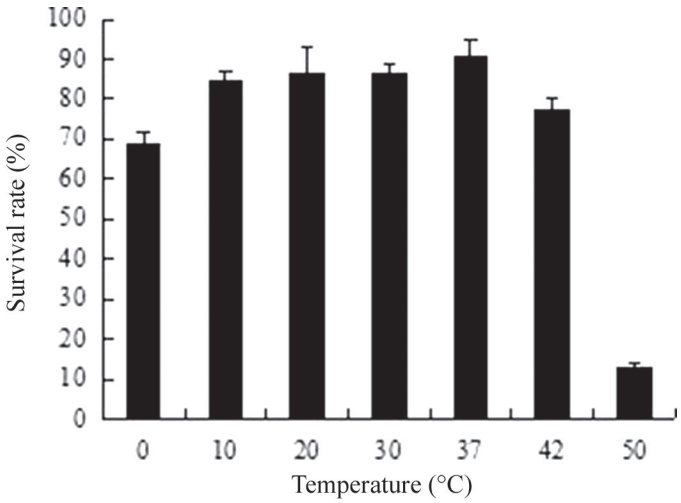

Figure 3. Survival rate of phage P2 after 30 min in de Man, Rogosa and Sharpe broth at different temperatures. The values are the mean of 3 determinations. Error bars represent 95% CI.

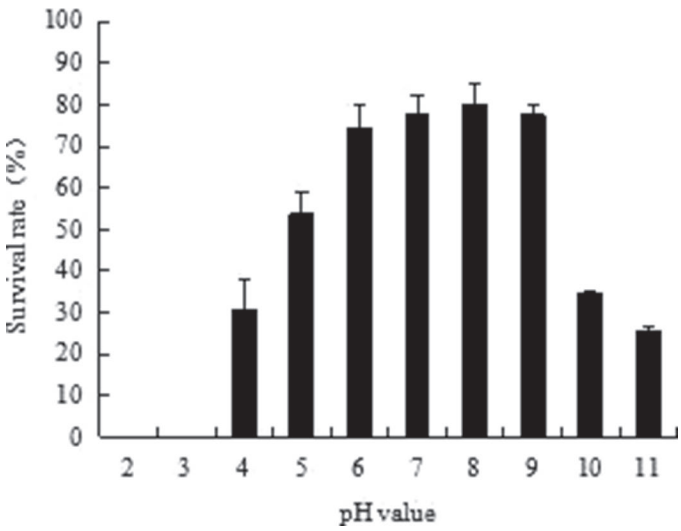

Figure 4. Effect of pH on survival rate of phage P2 in de Man, Rogosa and Sharpe broth after 30 min at 37°C. The values are the mean of 3 determinations. Error bars represent 95% CI.

because incubation at 50°C for 30 min still resulted in 95% viability (Chen et al., 2016). Briggiler Marcó et al. (2010) evaluated the influence of temperature (0, 10, 20, 30, 37, 42, and 50°C) on infectivity of 4 *L. plantarum* phages (B1, B2, FAGK1, and FAGK2). The author reported that these temperatures did not appear to influence the infectivity of these phages. In contrast to the results obtained in the present study, more than 95% of the initial phages remained viable after 30 min in MRS broth at 50°C.

Influence of pH on Phage Viability

As shown in Figure 4, more than 80% of the phages remained infective over a pH range from 6 to 9. However, decreases in phage viability at pH values below 6 and above 9 were quite apparent. No viable phage was observed at pH 2 to 3.

Influence of Temperature on Phage Adsorption

Figure 5 shows the influence of temperature on the adsorption of phage P2. Temperatures from 0 to 42°C did not appear to influence phage adsorption because more than 88% of phage particles were adsorbed after 30 min. Incubated at 50°C, unadsorbed phage particles increased to 31.33%. Similar to other *Lactobacillus* phages, the highest adsorption rate was achieved at 37°C (92.81%).

For the influence of temperature on phage adsorption of phage P2, similar results were previously reported for *L. plantarum* phages by Chen et al. (2016) and Briggiler Marcó et al. (2010). Chen et al. (2016) reported that more than 85% of phage P1 were adsorbed after 45 min at all temperatures tested (0, 10, 20, 30, 37, and 42°C) except at 50°C. Briggiler Marcó et al. (2010) evaluated the influence of temperature on the adsorption of 4 phages of *L. plantarum* ATCC8014. They found that more than 82% phage particles were adsorbed after 30 min in all the conditions studied except at 50°C, which caused an increase in the titers of

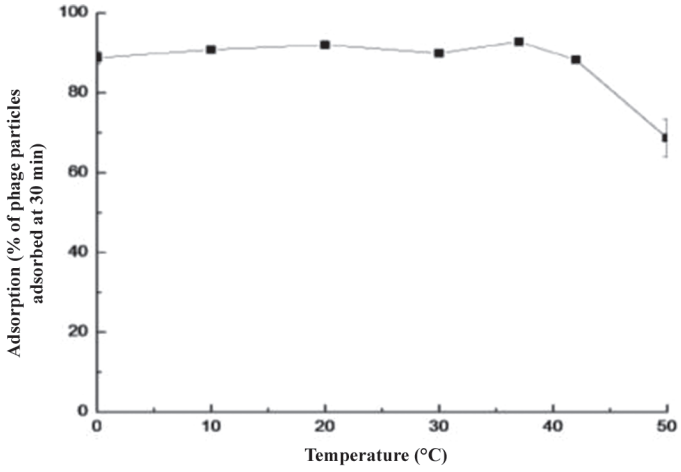

Figure 5. Influence of temperature on the adsorption of phage P2 after 30 min in de Man, Rogosa and Sharpe broth. Values are the means of 3 determinations. Error bars represent 95% CI.

unadsorbed phages particles (adsorption values <39%), and the maximum adsorption values were achieved at temperatures ranging from 30 to 42°C for all phages (Briggiler Marcó et al., 2010). For *L. paracasei* phages ΦiLp84 and ΦiLp 1308, the efficiency of adsorption was minimal at 0°C and increased with temperature up to 37°C (Mercanti et al., 2015). It has been suggested that the effect of temperature on phage propagation could be due to temperature-dependent changes in the bacterial cell wall. This could affect the adsorption of phages, and temperatures of 30 and 37°C may be more effective (Caso et al., 1995). Moreover, higher temperature may prolong the length of the latent stage (Tey et al., 2009).

Influence of pH on Phage Adsorption

The influence of pH on phage adsorption is shown in Figure 6. No significant ($P < 0.05$) effect on phage adsorption was observed from pH 5 to 9; in all cases adsorption approached 90%. In contrast, the adsorption rate decreased to approximately 77 and 67% at pH 4 and 10, respectively.

For the influence of pH on the viability and adsorption of *Lactobacillus* phages, similar results have been reported. For example, phage P1 also exhibited more than 90% survival at pH values from 6 to 8; however, only 1.2% survival was observed at pH 3 following 30 min incubation at 37°C. Moreover, more than 90% adsorption occurred from a pH of 4 to 8. When the pH increased to 11, the adsorption rate decreased to 7.78% after 45 min (Chen et al., 2016). For phages B1, B2, FAGK1, and FAGK2, the highest viability (>80%) was observed in a wider pH range (from 5 to 11); however, complete inactivation was observed after 30 min at pH 2. The highest adsorption values for these 4 phages occurred at pH 5 to 7 after 30 min at 37°C. At pH 9, the extent of adsorption for phage B1 ranged from 23% (phage B1) to 45% (phage B2), whereas at pH 10, the adsorption value was less than 20% (Briggiler Marcó et al., 2010). Sunthornthummas et al. (2017) reported that phage ΦT25 was also resistant to a wide range of pH; however, no survivors could be detected following incubation at pH 2 for 30 min at 37°C. Phage P2 was more sensitive to higher pH value than to lower pH value. Compared with previous results, the adsorption of phage P2 was more stable under high pH values. When the pH value increased to 11, its adsorption rate was still 61.14% after 30 min of treatment. Langlet et al. (2007) reported that MS2 phages showed significant ability to aggregate when the pH was less than or equal to the phage isoelectric point. This could cause a decline in phage count and the adsorption on membranes (Jończyk et al., 2011).

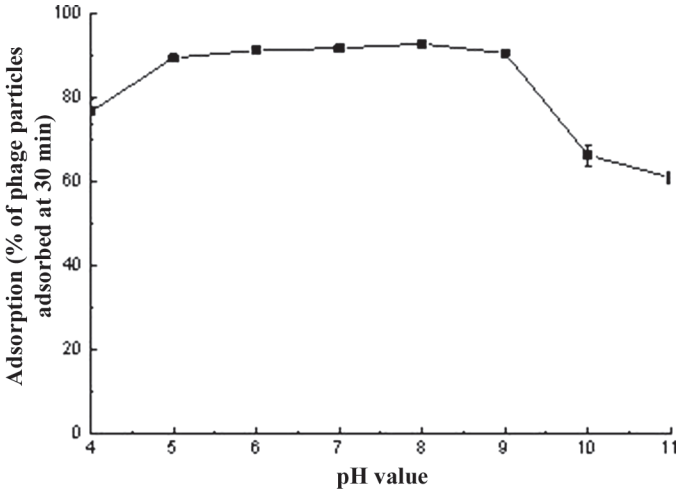

Figure 6. Influence of pH on the adsorption of phage P2 after 30 min in de Man, Rogosa and Sharpe broth. Values are the means of 3 determinations. Error bars represent 95% CI.

Influence of Divalent Cations on Phage Adsorption

Ca^{2+} or Mg^{2+} cations are recognized as necessary for proliferation of phages (Zhang et al., 2015). As shown in Figure 7, cell lysis in MRS broth occurred even without divalent cations but can form clear lysis plaques after 30-min treatments in the presence of Ca^{2+}. In general, calcium ions did not have a significant ($P > 0.05$) influence on phage adsorption kinetics (Figure 7).

For other reported phages, we found that the requirement of divalent cations for phage adsorption was variable. Similar to our reports, Briggiler Marcó et al. (2010) reported that divalent cations were not necessary for adsorption or completion of the lytic cycle of the 4

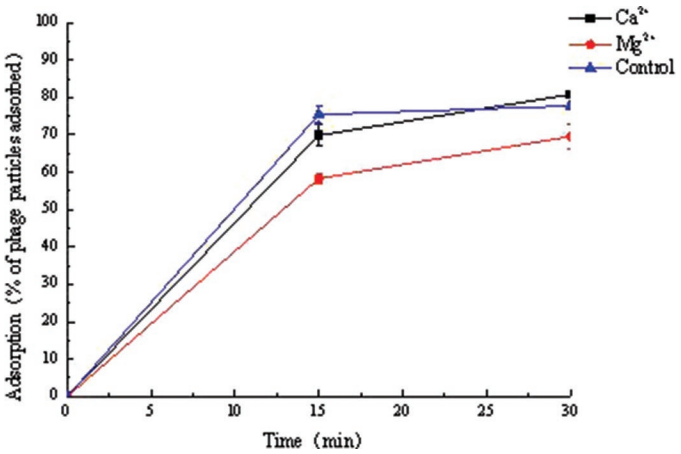

Figure 7. Influence of divalent cations on adsorption of phage P2 after 30 min at 37°C. Values are the mean of 3 determinations. Error bars represent 95% CI.

L. plantarum phages (B1, B2, FAGK1, and FAGK2). In contrast, Zhang et al. (2015) found that although Ca^{2+} and Mg^{2+} were not necessary for the completion of the lytic cycle of phage Lcb of *Lactobacillus casei* ATCC393, they did improve complete lysis and plaque formation. Sunthornthummas et al. (2017) reported that the addition of calcium ions affected the adsorption of phage ΦT25 because maximum adsorption rates were observed in the presence of 20 m*M* calcium ions after 30 min of incubation. It was suggested that calcium ions could stabilize the DNA inside the phage capsid as well as control the penetration of phage DNA into host cells (Zhang et al., 2015).

Influence of Cell Protein Synthesis Inhibitors on Phage Adsorption

The chloramphenicol concentration used in this study was 20 μg/mL. The results showed that treatment of chloramphenicol did not affect its adsorption ($P > 0.05$) on cells compared with untreated cells. After 30 min of incubation, more than 90% of initial phage particles were adsorbed with or without chloramphenicol (data not shown). This result was similar to previous reports of *L. plantarum* phages (Briggiler Marcó et al., 2010; Chen et al., 2016). As previously reported, it would not be expected that phage binding is an energy-dependent process. Further studies will be needed to recognize the phage receptor sites.

CONCLUSIONS

A virulent phage P2 belonging to the *Siphoviridae* family was isolated from the abnormal fermented liquid of *L. plantarum* IMAU10120. This research revealed its important properties and evaluated the influence of physicochemical factors on its viability and adsorption rate. The latent period of this phage was 30 min with a burst time of 135 min. Its burst size was 214.5 ± 4.0 pfu/infective center. Temperatures of 10 to 37°C had little effect on its viability and adsorption. More than 90% of phages exhibited infectivity from pH 5 to 9. Divalent cations and chloramphenicol did not significantly affect its adsorption. Further studies will focus on researching the infective mechanism of this phage as well as effective strategies to control phage infections in industry.

ACKNOWLEDGMENTS

This work was supported by Natural Science Foundation of China (grant no. 31760447, 31301517, Beijing, China) and Natural Science Foundation of Inner Mongolia, China (grant no. 2017MS0308, 2013MS1207, Hohhot, China).

REFERENCES

Ackermann, H. W. 2007. 5500 phages examined in the electron microscope. Arch. Virol. 152:227–243.

Bebeacua, C., D. Tremblay, C. Farenc, M. Chapot-Chartier, I. Sadovskaya, M. van Heel, D. Veesler, S. Moineau, and C. Cambillau. 2013. Structure, adsorption to host, and infection mechanism of virulent lactococcal phage p2. J. Virol. 87:12302–12312.

Briggiler Marcó, M., J. A. Reinheimer, and A. Quiberoni. 2010. Phage adsorption to *Lactobacillus plantarum*: Influence of physiological and environmental factors. Int. J. Food Microbiol. 138:270–275.

Capra, M. L., A. Quiberoni, and J. Reinheimer. 2006. Phages of *Lactobacillus casei/paracasei*: Response to environmental factors and interaction with collection and commercial strains. J. Appl. Microbiol. 100:334–342.

Caso, J. L., C. G. D. L. Reyes-Gavilan, M. Herrero, A. Montilla, A. Rodriguez, and J. E. Suarez. 1995. Isolation and characterization of temperate and virulent bacteriophages of *Lactobacillus plantarum*. J. Dairy Sci. 78:741–750.

Chen, X., Y. Xi, H. Zhang, Z. Wang, M. Fan, Y. Liu, and W. Wu. 2016. Characterization and adsorption of *Lactobacillus* virulent phage P1. J. Dairy Sci. 99:6995–7001.

Cvirkaitė-Krupovič, V., M. Krupovič, R. Daugelavičius, and D. H. Bamfor. 2010. Calcium ion-dependent entry of the membrane-containing bacteriophage PM2 into its *Pseudoalteromonas* host. Virology 405:120–128.

De Antoni, G., M. Zago, O. Vasek, G. Giraffa, D. Carminati, M. Briggiler Marcó, J. Reinheimer, and V. Suárez. 2010. *Lactobacillus plantarum* bacteriophages isolated from kefir grains: Phenotypic and molecular characterization. J. Dairy Res. 77:7–12.

Dieterle, M. E., C. Bowman, C. Batthyany, E. Lanzarotti, A. Turjanski, G. Hatfull, and M. Piuri. 2014. Exposing the secrets of two well-known *Lactobacillus casei* phages, J-1 and PL-1, by genomic and structural analysis. Appl. Environ. Microbiol. 80:7107–7121.

Ferrando, V., A. Quiberoni, J. Reinhemer, and V. Suárez. 2015. Resistance of functional *Lactobacillus plantarum* strains against food stress conditions. Food Microbiol. 48:63–71.

Garneau, J. E., and S. Moineau. 2011. Bacteriophages of lactic acid bacteria and their impact on milk fermentations. Microb. Cell Fact. 10(Suppl. 1):S20.

Giraffa, G., N. Chanishvili, and Y. Widyastuti. 2010. Importance of lactobacilli in food and feed biotechnology. Res. Microbiol. 161:480–487.

Jończyk, E., M. Klak, R. Międzybrodzki, and A. Górski. 2011. The influence of external factors on bacteriophages—Review. Folia Microbiol. (Praha) 56:191–200.

Langlet, J., F. Gaboriaud, and C. Gantzer. 2007. Effects of pH on plaque forming unit counts and aggregation of MS2 bacteriophage. J. Appl. Microbiol. 103:1632–1638.

Mahony, J., C. Cambillau, and D. van Sinderen. 2017. Host recognition by lactic acid bacterial phages. FEMS Microbiol. Rev. 41:S16–S26.

Mahony, J., D. M. Tremblay, S. J. Labrie, S. Moineau, and D. van Sinderen. 2015. Investigating the requirement for calcium during lactococcal phage infection. Int. J. Food Microbiol. 201:47–51.

McCabe, O., S. Spinelli, C. Farenc, M. Labbé, D. Tremblay, S. Blangy, S. Oscarson, S. Moineau, and C. Cambillau. 2015. The targeted recognition of *Lactococcus lactis* phages to their polysaccharide receptors. Mol. Microbiol. 96:875–886.

Mercanti, D. J., H. W. Ackermann, and A. Quiberoni. 2015. Characterization of two temperate *Lactobacillus paracasei* bacteriophages: Morphology, kinetics and adsorption. Intervirology 58:49–56.

Munsch-Alatossava, P., and T. Alatossava. 2013. The extracellular phage-host interactions involved in the bacteriophage LL-H infection of *Lactobacillus delbrueckii* ssp. *lactis* ATCC 15808. Front. Microbiol. 4:408.

Neviani, E., D. Carminati, and G. Giraffa. 1992. Selection of some bacteriophage and lysozyme-resistant variants of *Lactobacillus helveticus* CNRZ 892. J. Dairy Sci. 75:905–913.

Quiberoni, A., V. B. Suárez, A. G. Binetti, and J. A. Reinheimer. 2011. Bacteriophage. Pages 430–438 in Encyclopedia of Dairy Science. 2nd ed. Vol. 1. J. Fuquay, P. Fox, and P. McSweeney, ed. Academic Press, Wageningen, the Netherlands.

Rakhuba, D. V., E. I. Kolomiets, E. S. Dey, and G. I. Novik. 2010. Bacteriophage receptors, mechanisms of phage adsorption and penetration into host cell. Pol. J. Microbiol. 59:145–155.

Samson, J. E., and S. Moineau. 2013. Bacteriophages in food fermentations: New frontiers in a continuous arms race. Annu. Rev. Food Sci. Technol. 4:347–368.

Sunthornthummas, S., K. Doi, A. Rangsiruji, S. Sarawaneeyaruk, and O. Pringsulaka. 2017. Isolation and characterization of *Lactobacillus paracasei* LPC and phage ΦT25 from fermented milk. Food Control 73:1353–1361.

Tey, B. T., S. T. Ooi, K. C. Yong, M. Ng, T. C. Ling, and W. S. Tan. 2009. Production of fusion M13 phage bearing the di-sulphide constrained peptide sequence (C-WSFFSNI-C) that interacts with hepatitis B core antigen. Afr. J. Biotechnol. 8:268–273.

Villion, M., and S. Moineau. 2009. Bacteriophages of *Lactobacillus*. Front. Biosci. (Landmark Ed.) 14:1661–1683.

Vries, M. C. D., E. E. Vaughan, M. Kleerebezem, and W. M. D. Vos. 2006. *Lactobacillus plantarum*—Survival, functional and potential probiotic properties in the human intestinal tract. Int. Dairy J. 16:1018–1028.

Zhang, X., Y. Lan, W. Jiao, Y. Li, L. Tang, Y. Jiang, W. Cui, and X. Qiao. 2015. Isolation and characterization of a novel virulent phage of *Lactobacillus casei* ATCC 393. Food Environ. Virol. 7:333–341.