DETERMINATION OF SOME PHYSICAL AND MECHANICAL PROPERTIES OF ONION / 洋葱基本物理力学特性测定

Hongguang YANG, Bing WANG, Fengwei GU, Feng WU, Yanhua ZHANG, Zhichao HU* [1]
Nanjing Institute of Agricultural Mechanization, Ministry of Agriculture and Rural Affairs, Nanjing, 210014/China
Tel: +86-025-84346256; E-mail: 1432245697@qq.com
DOI: https://doi.org/10.35633/inmateh-68-32

Keywords: *onion, bulb, cauloid, physical properties, mechanical properties*

ABSTRACT
Lack of sufficient knowledge about the physical and mechanical properties of onion can result in higher waste during harvesting and post-harvesting. The objective of this work was to determine some physical and mechanical properties of onion cultivated in China. These properties include linear dimensions, mass, shape index, pull-out force, compression and shear forces. The mean longitudinal diameter of bulb (BLD), transverse diameter of bulb (BTD), bulb weight (BW), pull-out force of bulb (BPF), depth of the bulb buried in the soil (BSD), bulb shape index (BSI), diameter of cauloid (CD), circumferential distribution of root systems (RCD), longitudinal length of root systems (RLL) and weight of root systems (RW) were 78.1±9.6 mm, 89.6±10.1 mm, 333.0±101.7 g, 43.9±21.6 N, 35.7±8.7 mm, 1.2±0.1, 15.3±3.7 mm, 89.2±19.7 mm, 42.9±10.0 mm and 0.8±0.4 g. In the study of mechanical properties of onions, the maximum compression force (MCF) required for compression deformation 10 mm of bulb was 462.2 N, and the maximum shear failure force (MSF) required for shearing of cauloid was 113.8 N. The results of the research will be very useful in the design and optimization of harvest and postharvest machines with reduced waste and damage.

摘要
由于对洋葱基本物理力学特性缺乏充分认知，经常会在收获和产后加工处理时产生较高的浪费。本研究的目标是确定中国栽培洋葱的一些基本物理力学特性。这些特性主要包括线性尺寸、重量、形状、起拔力、压缩力和剪切力。试验结果表明，洋葱鳞茎纵向平均直径、横向平均直径、重量、起拔力、入土深度、形状指数、假茎直径和根系周向分布直径、长度及重量分别为 78.1±9.6 mm、89.6±10.1 mm、333.0±101.7 g、43.9±21.6 N、35.7±8.7 mm、1.2±0.1、15.3±3.7 mm、89.2±19.7 mm、42.9±10.0 mm 和 0.8±0.4 g。力学特性试验表明，洋葱鳞茎压缩变形 10mm 所用压缩力平均值为 462.2N，洋葱假茎剪切破坏所用剪切力平均值为 113.8 N。研究结果对于设计优化洋葱收获和产后加工机械及减少损伤浪费有重要价值。

INTRODUCTION
Onion is one of the most economically important vegetable crops grown in China (*Ren et al, 2021; Wang et al, 2021*). The scientific name of it is Allium cepa L. which belongs to the family of Liliaceae. Although it has only been cultivated in China for more than 100 years, it is widely grown in different parts of the country (*Yang et al, 2019*). China, India, United States, Iran, Egypt and Russia are the main producers of onions in the world (*Zhang et al, 2022; Bisen et al, 2013*). China is the largest onion growing country in the world with the production of 23.7 million tons in 2020 under the area of 1.1 million ha (Data from the FAOSTAT database of the Food and Agricultural Organization (FAO) of the United Nations).

The physical and mechanical properties of agricultural products are very important. Lack of sufficient knowledge about the physical and mechanical properties of agricultural products can result in higher waste of them (*Jahanbakhshi et al, 2018*). Meanwhile, a detailed understanding of these can better design and optimize the relevant production and processing machinery. For example, *Jahanbakhshi et al.,* (*2018*), studied the physical and mechanical properties of carrot. *Kibar and Öztürk,* (*2008*), studied the physical and mechanical properties of soybean under different moisture content. Wang et al. (*Wang et al, 2019*) tested the tensile properties of Nagafu apple, Crisp pear, Tainong mango and long eggplant. *Li et al.*, (*2018*) reported that the mechanical properties and microstructure of potato peels. *Jithender et al.,* (*2017),* studied the physical and mechanical properties of pomegranate fruit and aril.

[1] *Hongguang Yang, MS.Eng.; Bing Wang, MS.Eng.; Fengwei Gu, MS.Eng.; Feng Wu, Prof.; Yanhua Zhang, MS.Eng.; Zhichao Hu *, Prof..*

Sagsoz and Alayunt, (*2001*), analysed the several methods for measuring the modulus of elasticity of onion bulb. *Cakir et al.,* (*2001*), tested the compression properties of onion bulbs. *Essa and Gamea,* (*2003*), tested the physical and mechanical properties of onion bulbs. *Bahnasawy et al, (2004*), estimated the physical and mechanical properties of the most popular cultivars (Giza 6, Beheri and Giza 20) of onion in Egypt. *Dabhi and Patel,* (*2017*), estimated the physical and mechanical properties of Talaja Red onion cultivar. *Karthik et al, (2016*), studied the physical, frictional and mechanical properties of the three popular onion varieties (Satara Garva, Arka Kalyan and Bangalore rose) in India.

Numerous studies have been carried out on the physical and mechanical properties of different agricultural products. However, there are few reports on the physical and mechanical properties of onion cultivated in China. It is due to the lack of much knowledge about the physical and mechanical properties of onion in China and how to reduce its waste as well as design and optimize the required harvesting and post-harvesting machinery. This study aims to contribute to fill this research gap. The main objective of this study is to investigate some physical and mechanical properties of bulbs, roots and cauloids of onion plants. These properties include linear dimensions, mass, shape index, pull-out force, compression and shear forces.

MATERIALS AND METHODS

Determination of some physical properties and pull-out force of onion

The test was conducted in the vegetable planting base in Ulanqab City of Inner Mongolia Autonomous Region of China. The planting pattern of onion is bed planting. There are eight rows in a bed. The bed width is 1300 mm and the distance is 1900 mm. The row spacing of onion on the bed is 15 mm and the plant spacing is 17 mm. The soil type is sandy loam (artificially improved soils). The mean soil compaction and moisture content at depths of 0 cm to 5 cm are 1093.3 kPa and 10.3% respectively. The mean soil compaction and moisture content at depths of 5 cm to 10 cm are 1213.3 kPa and 12.8% respectively.

The onion was planted in the middle of May. The variety is Red Hydrangea. It is a long-day variety with bright purplish red skin which has a growth period of about 170 days and plant height of 60 cm to 70cm. This variety of onion is widely cultivated in China, especially the northern part of the country. The test field and planting pattern of onion are shown in Figure 1.

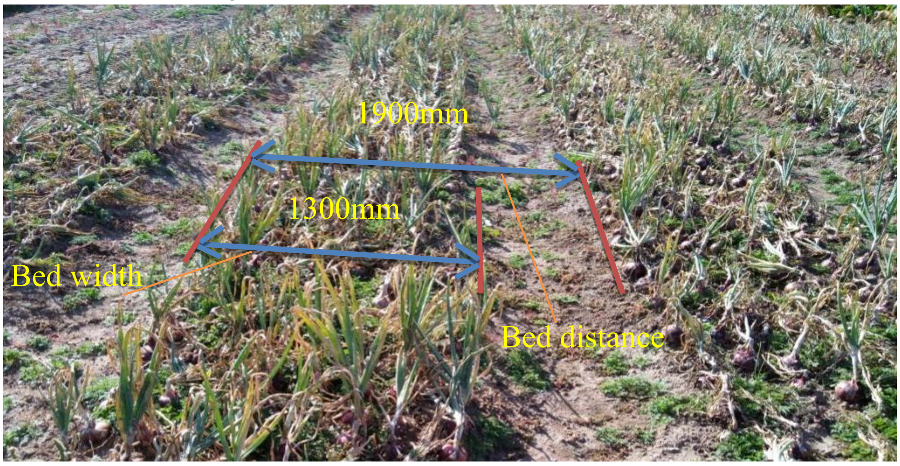

Fig. 1 - Test field and planting pattern of onion

The test instruments for this study are electronic digital display vernier caliper (Model: Guilin, manufacturer: Guilin Guanglu Measuring Instrument Co., Ltd., measuring range: 0 mm to 150 mm, measurement accuracy: 0.01 mm), electronic balance (Model: NS, manufacturer: Fuzhou HUAKE Electronic Instruments Co., Ltd., measuring range: 0 kg to 6 kg, measurement accuracy: 0.1 g), electronic hanging scale (Model: OCS-L, manufacturer: Hangzhou Tianchen Scale Equipment Co., Ltd., measuring range: 0.2 kg to 30 kg, measurement accuracy: 0.01 kg), steel ruler (Model: GWR, manufacturer: Ningbo Great Wall Precision Industrial Co.,Ltd., measuring range: 0 mm to 300 mm, measurement accuracy: 1 mm).

In this experimental study, the main measurement objects of onion plants mainly include the mean longitudinal diameter of bulb (BLD), transverse diameter of bulb (BTD), bulb weight (BW), pull-out force of bulb (BPF), depth of the bulb buried in the soil (BSD), bulb shape index (BSI), diameter of cauloid (CD), circumferential distribution of root systems (RCD), longitudinal length of root systems (RLL) and weight of root systems (RW).

As shown in Figure 2, BLD is the distance between the onion crown and the point of root attachment to the onion. BTD is the maximum width of the onion bulb in a plane perpendicular to the BLD. BSD is the depth at which onion bulb grow under the soil. CD is the diameter of 2 cm away from the junction of onion crown and cauloid. RCD is the diameter of the circumferential distribution of root systems measured after onion bulbs are pulled out. RLL is the maximum length of root systems measured after onion bulbs are pulled out. RW is the weight of root systems measured after onion bulbs are pulled out. BW is the weight of a single onion bulb. BPF is the force used to pull-out the bulb form the soil.

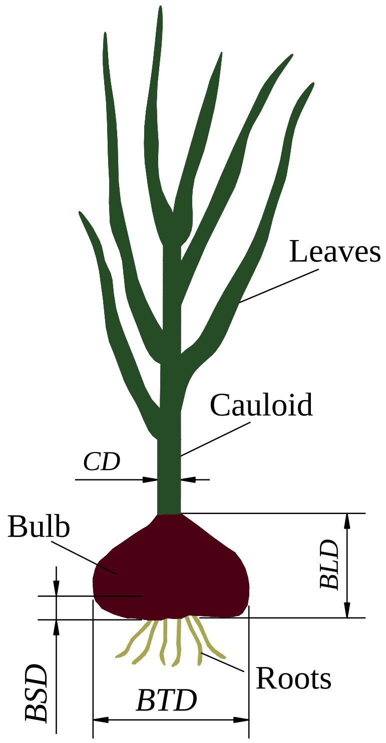

Fig. 2 - Schematic diagram of onion plant

In addition, BSI is used to evaluate the shape of onion bulbs and it is calculated according to the equation (1). The onion bulb is considered an oval if the BSI >1.5, on the other hand, it is considered spherical if the BSI <1.5 (*Cakir et al, 2016*).

$$BSI = \frac{BTD}{BLD} \tag{1}$$

During the experiment, 50 onion plants were randomly selected as the test object. Firstly, the BPF in natural growth of onion plants during harvest was measured by electronic hanging scale. Then, vernier caliper, electronic balance and steel ruler were used to measure and calculate the BLD, BTD, BW, BPF, BSD, BSI, CD, RCD, RLL and RW. Finally, the measured data were statistically analysed by MS-Excel.

Determination of compression properties of onion bulb

As we all know, the most commonly used mechanical properties of agricultural products is compression characteristics. Compression damage is the main reason for the loss of agricultural products. Therefore, the compression test of onion bulb was carried out. However, because the bulb has its own shape (composed of layers of fleshy scales), it is heterogeneous and isotropic. It cannot be made into regular sample (a cylindrical or a square shape), but can only be compressed as a whole.

Onion bulbs were taken from the test field. The mean moisture content of bulb is 88.9%. The compression test of bulb was carried out by electronic universal testing machine (Model: UTM6503, manufacturer: Shenzhen SUNS Technology Stock Co., Ltd., measuring range: 0 kN to 5 kN). The indenter of the testing machine is round, with a diameter of 100 mm and a thickness of 20 mm. The testing machine and some onion bulbs for testing are shown in Figure 3.

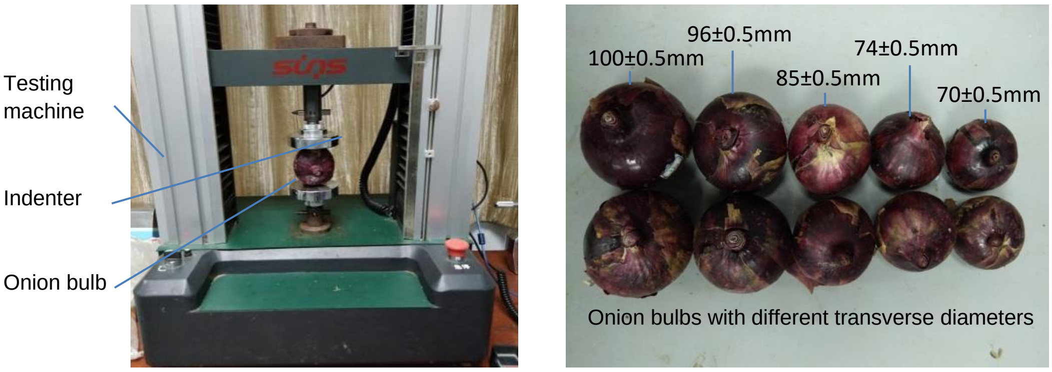

Fig. 3 - Compression test and some onion bulbs

Taking the BTD and the compression speed (CS) of the testing machine as the test factors, the maximum compression force (MCF) of 10 mm compression deformation of bulb is the test index. The quadratic general rotary unitized test was carried out. There are 13 groups of tests in total. According to the measured transverse diameter of onion bulb (mostly concentrated in 70 mm-100 mm, accounting for more than 85% of the total) and the compression test of relevant agricultural products (Aprilia *et al, 2021*), the test factor code and value are designed as shown in Table 1. Through the analysis of the test results, the influence law of the BTD and CS on the MCF is revealed. In order to facilitate the analysis of test results, the coded values of BTD and CS are recorded as A and B respectively.

Table 1

Factors and levels of compression test

levels	**Factors**	
	BTD	**CS**
	[mm]	**[mm/min]**
-1.414	70±0.5	10
-1	74.4 (74±0.5)	23.2 (23)
0	85±0.5	55
1	95.6 (96±0.5)	86.8 (87)
1.414	100±0.5	100

Determination of shear properties of onion cauloid

The shear properties of onion cauloids which were taken from the experimental field were tested by universal testing machine. The testing machine and some onion cauloids for testing are shown in Figure 4. Among them, the effective working width of the cutter of testing machine is 25 mm, the height is 23 mm, the thickness is 3 mm, and the height of the cutter tip is 10 mm. The effective length of onion cauloid samples are 80±0.5 mm. The CD, the moisture content (MC) of onion cauloid and the shear speed (SS) of the testing machine are selected as the test factors. The maximum shear failure force (MSF) is selected as the test index. Three-factor and three-level orthogonal test was carried out.

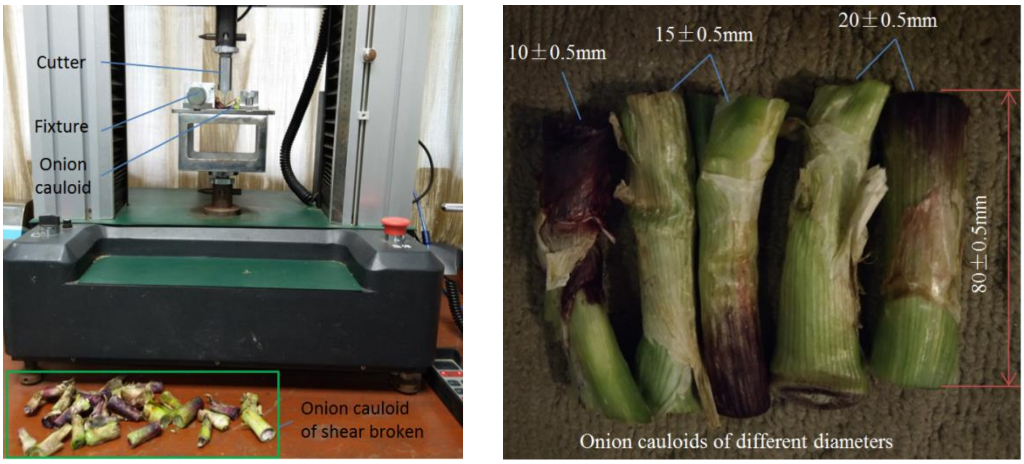

Fig. 4 - Shear test and some onion cauloids

The moisture content of onion cauloid on the sampling day was taken as level 1. The moisture content after one day and two days of natural drying was regarded as level 2 and level 3. Through actual measurement, the mean moisture content of cauloid on the day of sampling, natural drying for one day and two days is 88.9%, 74.0% and 68.5%, respectively. At the same time, according to the measurement of cauloid diameter in the experimental field (mostly concentrated in 10 mm-20 mm, accounting for more than 75% of the total) and relevant shear characteristic tests (*Xin et al, 2020*), the arrangement of each factor is shown in Table 2. An L_9 (3^4) orthogonal table was established, in which C, D, and E are the coding values of each factor level.

Table 2

Factors and levels of shear test

levels	Factors		
	CD [mm]	MC [%]	SS [mm/min]
1	10±0.5	68.5	10
2	15±0.5	74.0	20
3	20±0.5	88.9	30

RESULTS

Determination of some physical properties and pull-out force of onion

Figure 5 shows the mean values, maximum, minimum, standard deviation (SD) and coefficient of variation (CV) of the BLD, BTD, BW, BPF, BSD, BSI, CD, RCD, RLL and RW.

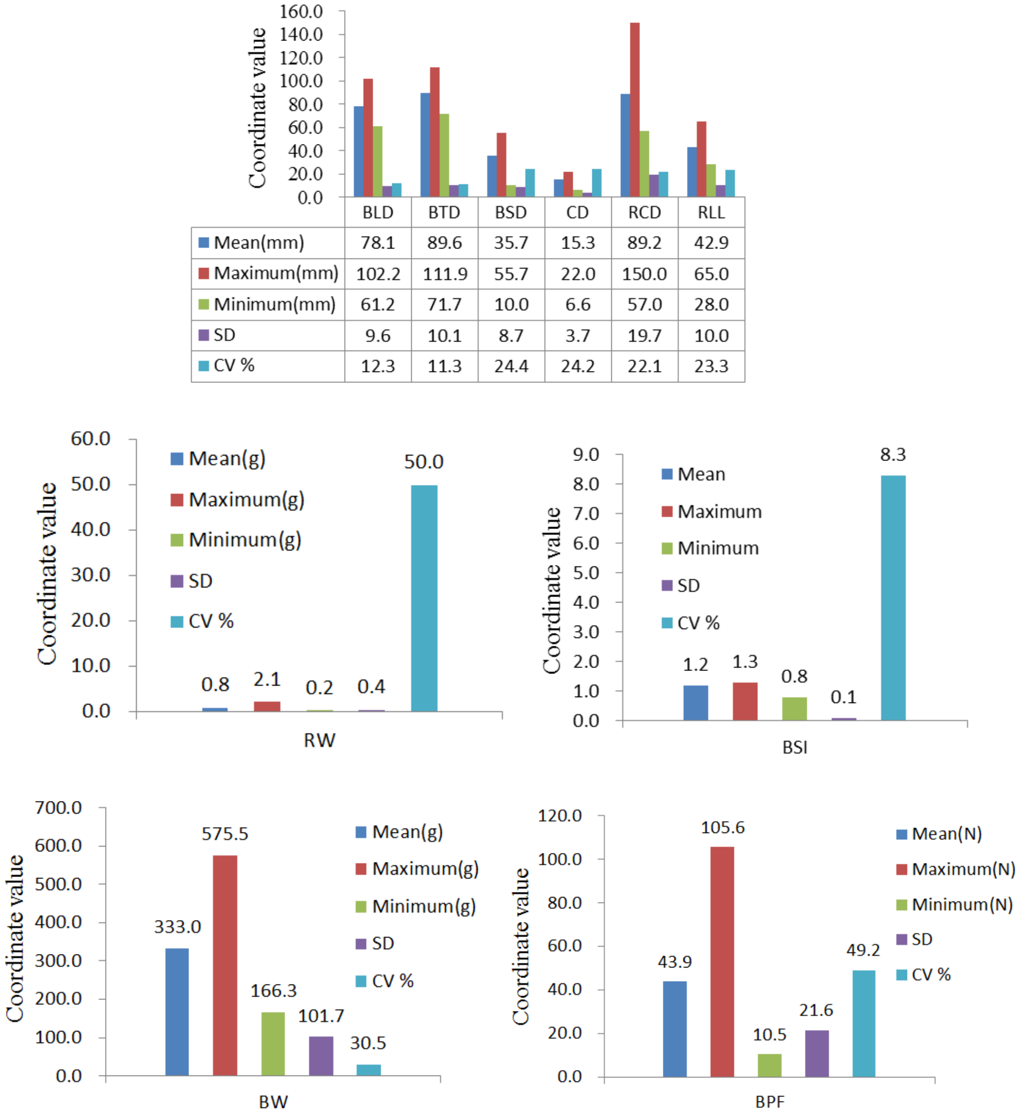

Fig. 5 - Mean values, maximum, minimum, SD and CV of onion

As can be seen from Figure 5, the mean of the BLD, BTD, BW, BPF, BSD, BSI, CD, RCD, RLL and RW are 78.1±9.6 mm, 89.6±10.1 mm, 333.0±101.7 g, 43.9±21.6N, 35.7±8.7 mm, 1.2±0.1, 15.3±3.7 mm, 89.2±19.7 mm, 42.9±10.0 mm and 0.8±0.4 g, respectively. According to the equation (1), the onion bulb is considered an oval if the shape index > 1.5, on the other hand, it is considered spherical if the shape index <1.5. Hence, it indicated that the onion bulb of Red Hydrangea was a spherical in shape. And the CV of the BLD value was higher than that of BTD. This result was in agreement with those reported by Bahnasawy et al. (*Bahnasawy et al, 2004*) and Dabhi et al. (*Dabhi et al, 2017*). During the pull-out test, it was found that the cauloids of several onion plants were broken. The reason may be that the force required to pull-out onion bulb exceeds the breaking force limit of cauloid. It can be seen that it was difficult to harvest onions in the natural growth state by direct extraction, and some auxiliary excavation work was necessary (*Kumawat et al, 2022; Joshi et al, 2020*).

Determination of compression properties of onion bulb

The compression test results are shown in Table 3. When the bulb compression de-formation is 10 mm, the mean value of MCF measured in 13 groups of tests is 462.2 N, the standard deviation is 45.0, and the coefficient of variation is 9.7%. The analysis of variance of test results is shown in Table 4.

Table 3

Test scheme and results of compression test

Test No.	1	2	3	4	5	6	7	8	9	10	11	12	13
A	1	1	-1	-1	-	1.414	0	0	0	0	0	0	0
B	1	-1	1	-1	0	0	-	1.414	0	0	0	0	0
***MCF* [N]**	502.6	505.4	510.2	417.0	412.5	492.6	494.4	529.7	455.9	437.2	437.3	374.5	439.6

Table 4

Analysis of variance of compression test

Source	Sum of squares	*d*	Partial correlation	*F*-value	*P*-value	Significance
A	4708.31	1	0.72	7.69	0.03	**
B	2461.27	1	0.60	4.02	0.09	*
***A*²**	1035.41	1	0.44	1.69	0.24	
***B*²**	12242.11	1	0.86	20.01	0.00	***
AB	2304.00	1	-0.59	3.77	0.09	*
Regression	22036.06	5	F_2=7.20			
Residual	4283.47	7				
Lack of fit	341.17	3	F_1=0.12			
Pure Error	3942.30	4				
Correlation total	26319.52	12				

Note: The critical value of significant judgment $F_{0.1}(1,7)=3.59$, $F_{0.05}(1,7)=5.59$, $F_{0.01}(1,7)=12.25$, $F_{0.1}(5,7)=2.88$, F0.05(5,7)=3.97, $F_{0.01}(5,7)=7.46$, $F_{0.1}(3,4)=4.19$, $F_{0.05}(3,4)=6.59$, $F_{0.01}(3,4)=16.69$.

** indicates that the factors have some influence on the test index ($0.05 < p \le 0.1$),*

*** indicates that the factors have a significant influence on the test index ($0.01 < p \le 0.05$),*

**** indicates that the factors have a very significant influence on the test index ($p \le 0.01$).*

From Table 4, it can be seen that F_2 =7.20>$F_{0.05}$ (5, 7) = 3.97 and F_1 = 0.12<$F_{0.1}$ (3, 4) = 4.19. The regression equation and lack of fit are credible under the condition of 95% confidence level. The regression coefficient analysis showed that the first item *B*, interaction item *AB* have some influence, first item *A* has a significant influence, square item B^2 has a very significant influence. From the results of analysis of variance, it can be seen that the influence order of various factors on MCF is *A* > *B*.

Set one of the factors to the zero level for single factor effect analysis. The results are shown in Figure 6. When CS is zero, MCF increases with the increase of BTD, and the two meet the linear relationship. When BTD is zero, MCF first decreases and then increases with the increase of CS, and the two meet the quadratic polynomial relationship.

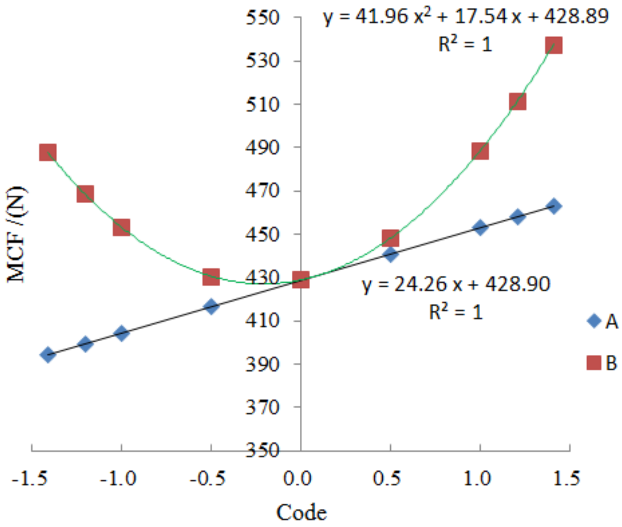

Fig. 6 - Single factor effect

It can be seen from table 4 that the interaction of the two factors has a significant impact on the test index. As shown in Figure 7, it is a three-dimensional response surface diagram of the interaction of two factors. As can be seen from Figure 7, when the value of CS is certain, MCF increases with the increase of BTD. When the value of BTD is certain, MCF first decreases slowly and then increases rapidly with the increase of CS.

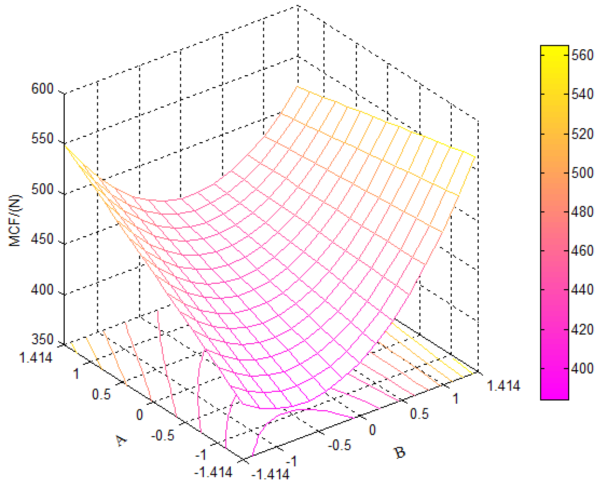

Fig. 7 - Interaction effect of two factors

Determination of shear properties of onion cauloid

The shear test results are shown in Table 5. The range analysis and analysis of variance of the test results are shown in Figure 8 and Table 6.

Table 5

Test scheme and results of shear test

Test No.	Factors				MSF [N]
	C	***D***	***E***	**Empty column**	
1	1	1	1	1	105.6
2	1	2	2	2	82.7
3	1	3	3	3	73.2
4	2	1	2	3	143.7
5	2	2	3	1	133.3
6	2	3	1	2	87.0
7	3	1	3	2	163.0
8	3	2	1	3	127.3
9	3	3	2	1	108.1

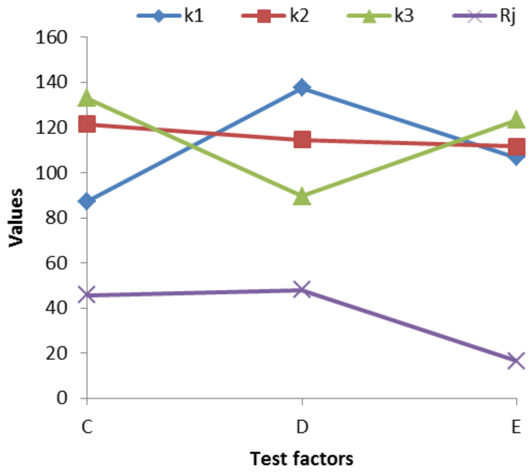

Fig. 8 - Range analysis of test results

Table 6

Analysis of variance

Indexes	Variance Source	Sum of Squares	Free Degree	*F*-Value	*p*-Value	Significance
MSF	*C*	3381.25	2	88.31	0.011	**
	D	3458.00	2	90.32	0.011	**
	E	433.15	2	11.31	0.081	*
	Error	38.29	2			

Note: The critical value of significant judgment $F_{0.01}(2,2) = 99.00$, $F_{0.05}(2,2) = 19.00$, $F_{0.1}(2,2) = 9.00$.
** indicates that the factors have some influence on the test index ($0.05 \le p < 0.1$),*
*** indicates that the factors have a significant influence on the test index ($0.01 \le p < 0.05$),*
**** indicates that the factors have a very significant influence on the test index ($p < 0.01$).*

From the results of range analysis and analysis of variance, it can be seen that the influence order of various factors on MSF is *D>C>E*. The mean value of MSF measured in 9 groups of tests is 113.8N, the standard deviation is 27.0, and the coefficient of variation is 23.7%. The mean shear strength of onion cauloid is 0.64 MPa. Obtaining the shear strength of onion cauloid is the key basis for the design of onion topper and combine harvester (*Yang et al, 2019; Joshi et al, 2020*).

At the same time, the results showed that the higher the moisture content of onion cauloid, the smaller the force to cut it. This result was in agreement with the reported shear characteristics of potato seedlings by Xin et al. (*Xin et al, 2020*). The main reason may be that when the moisture content is high, the stem is brittle and the force required to cut it is small.

CONCLUSIONS

This work focuses on some physical and mechanical properties of Red Hydrangea cultivar of the onions. The physical properties of the mean BLD, BTD, BW, BPF, BSD, BSI, CD, RCD, RLL and RW were 78.1±9.6 mm, 89.6±10.1 mm, 333.0±101.7 g, 43.9±21.6N, 35.7±8.7 mm, 1.2±0.1, 15.3±3.7 mm, 89.2±19.7 mm, 42.9±10.0 mm and 0.8±0.4 g. The shape of the onion bulbs may be considered spherical. The mechanical properties were the compression properties of onion bulb and the shear properties of onion cauloid. The maximum forces required for compression deformation 10 mm of the onion bulb was 462.2 N. The maximum forces required for shearing of the onion cauloid was 113.8 N, and the mean shear strength of cauloid was 0.64 MPa. The influence order of various factors on MCF was transverse diameter of the bulb and compression speed. The influence order of various factors on the MSF was moisture content, diameter of the cauloid and shear speed.

This study makes up for the lack of research on the basic physical and mechanical properties of onion cultivated in China, and can provide a reference for optimization design of harvesting and post-harvesting machines. However, the current research is only carried out for one variety of onion. In the next step, our research group will select multiple onion varieties for comparative research, and strive to form a basic database of physical and mechanical properties of Chinese onion.

ACKNOWLEDGEMENT

This research was funded by the Agricultural Science and Technology Innovation Programme (ASTIP) of the Chinese Academy of Agricultural Sciences (CAAS), grant number 31-NIAM-02; The Central Public Interest Scientific Institution Basal Research Fund, grant number S202110-02.

REFERENCES

[1] Aprilia, G., Triawan, F., Saville, R. (2021), Crispness measurement of potato crisps by single specimen using compression test. IOP Conference Series: *Materials Science and Engineering*, vol. 1098, no. 062100.

[2] Bahnasawy, A., El-Haddad, A., El-Ansary, M., et al, (2004), Physical and mechanical properties of some Egyptian onion cultivars. *Journal of Food Engineering*, vol. 62, pp. 255-261.

[3] Bisen, D., Kudnar, N. (2013), The production, export and catchment areas market of onion in Indian agriculture. *Research Expo International Multidisciplinary Research Journal*, no. 3, pp. 39-44.

[4] Cakir, E., Alayunt, F., Kurpinar, E. (2001), Dimensional analysis of mechanical behaviour of some onion varieties. *Journal of Biological Sciences*, no. 1, pp.925-928.

[5] Dabhi, M., Patel, N. (2017), Physical and mechanical properties of Talaja Red onion cultivar. *Bioprocess Engineering*, no. 1, pp. 110-114.

[6] Essa, A., Gamea, G. (2003), Physical and mechanical properties of bulb onions. *Misr Journal of Agricultural Engineering*, vol. 20, pp.661-676.

[7] Jahanbakhshi, A., Abbaspour-Gilandeh, Y., Gundoshmian, T. (2018), Determination of physical and mechanical properties of carrot in order to reduce waste during harvesting and post-harvesting. *Food Science & Nutrition*, no.6, pp.1898-1903.

[8] Jithender, B., Vyas, D., Abhisha, S., et al, (2017), Determination of physical and mechanical properties of pomegranate (Var. bhagwa) fruit and aril. *International Journal of Current Microbiology and Applied Sciences*, no. 6, pp.879-885.

[9] Joshi, S., Sathe S., Joshi, S., et al, (2020), Design, development and FEA of 3-point actuated digging and conveyor system for self-propelled onion harvester. *International Journal of Engineering and Technical Research*, no.9, pp.888-891.

[10] Karthik, S., Kumar, S., Palanimuttu, V. (2016), Engineering properties of some Indian onion cultivars. *International Journal of Agriculture Sciences*, no. 8, pp.1613-1617.

[11] Kibar, H., Öztürk, T. (2008), Physical and mechanical properties of soybean. *International Agrophysics*, vol. 22, pp. 239-244.

[12] Kumawat, L., Raheman, H. (2022), Mechanization in onion harvesting and its performance: a review and a conceptual design of onion harvester from Indian perspective. *Journal of the Institution of Engineers (India): Series A*, vol. 103, pp. 295-304.

[13] Li, J., Ma, Y., Tong, J., et al, (2018), Mechanical properties and microstructure of potato peels. *International Journal of Food Properties*, vol. 21, pp.1395-1413.

[14] Ren, F., Zhou, S. (2021), Phenolic components and health beneficial properties of onions. *Agriculture*, vol. 11, no. 872.

[15] Sagsoz, S., Alayunt, F. (2001), Comparison of some methods to determine the modulus of elasticity of some onion varieties. *Journal of Biological Sciences*, no. 1, pp.798-800.

[16] Wang, J., Zheng, D., Cui, Q., et al, (2019), Study on tensile mechanical property and microstructure of fruit and vegetable peels. *INMATEH Agricultural Engineering*, vol. 59, pp.227-236.

[17] Wang, R., Zhou, L., Ren, X., et al, (2019), Optimization technology of layer mesh belt hot air drying of onion (洋葱带式热风干燥工艺优化). *Science and Technology of Food Industry*, vol. 42, pp.195-201.

[18] Xin, Q., Lv, Z., Liu, L., et al, (2020), Experimental study on maximum shear force per unit diameter of potato seedlings at mature stage (成熟期马铃薯秧的单位直径最大剪切力试验研究). *Journal of Agricultural Mechanization Research*, vol. 42, pp.176-180, 195.

[19] Yang, H., Wang, B., Peng, B., et al, (2019), Performance test and parameter optimization of net-chain type onion harvester. *International Agricultural Engineering Journal*, vol. 28, pp. 248-256.

[20] Zhang, S., Yang, H., Hui, L., et al, (2022), Status and trends of onion (Allium cepa L.) research based on bibliometric analysis (基于文献计量分析洋葱研究热点与趋势). *Journal of China Agricultural University*, vol. 27, pp.118-134.