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THE INFLUENCE OF MOISTURE CONTENT ON POPPING TRAITS IN POPCORN

UTICAJ SADRŽAJA VLAGE NA OSOBINE KOKANJA KOD KUKURUZA KOKIČARA

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ABSTRACT

The influence of grain moisture content at harvest and at the moment of popping on popping volume and percentage of unpopped kernels was analysed. Four popcorn hybrids were studied. Hybrids were harvested when grain moisture content was: above 25%, between 20 – 25%, and below 18%. Each sample was popped at 20%, 18%, 16%, 14%, 12%, and 10% of grain moisture. All examined factors and their interactions significantly influenced both popping volume and percentage of unpopped kernels. The highest popping volume and the lowest percentage of unpopped kernels were observed at 14% grain moisture content. Hybrid ZP 608k had the highest popping volume and the lowest percentage of unpopped kernels at all treatments and overall. The lowest popping volume and the highest percentage of unpopped kernels were noticed for ZP 501k. The lowest percentage of unpopped kernels was observed in the last harvest term when grain moisture content was below 18%.

Key words: *popcorn, grain moisture content, popping volume, percentage of unpopped kernels.*

REZIME

Zapremina kokičavosti je pored potencijala rodnosti najvažnija osobina hibrida kokičara. Više faktora utiče na nju: genotip, uslovi proizvodnje, dorade i čuvanja zrna, kao i metode kokanja. Maksimalan potencijal zapremine kokičavosti postiže se samo ako je hibrid dostigao punu zrelost. Ipak, najvažniji je uticaj sadržaja vlage u trenutku kokanja. Sadržaj vlage od oko 14% je optimalan i pri njemu se ostvaruju najviše zapremine kokičavosti. U radu je ispitivan uticaj sadržaja vlage u zrnu prilikom berbe i u trenutku kokanja na osobine kokičavosti: zapremina kokičavosti i procenat neiskokanog zrna. Ove osobine proučavane su na na četiri hibrida kukuruza kokičara. Hibridi su brani u tri termina pri sadržaju vlage: preko 25%, između 20 – 25%, i nižoj od 18%. Zatim je svaki od uzoraka kokan pri sadržaju vlage od 20%, 18%, 16%, 14%, 12%, i 10%. Analiza varijanse ukazala je na značajan uticaj genotipa, sadržaja vlage prilikom berbe, kao i interakcija na zapreminu kokičavosti i procenat neiskokanog zrna. Najviša zapremina kokičavosti ostvarena je pri sadržaju vlage od 14%, a takođe pri ovom sadržaju vlage najmanji je bio i procenat neiskokanog zrna. Hibrid ZP 608k je imao najvišu zapreminu kokičavosti i najmanji procenat neiskokanog zrna, kako u proseku svih tretmana, tako i po proučavanim tretmanima, dok je najamnju zapreminu kokičavosti i najveći procenat neiskokanog zrna imao hibrid ZP 501k. Najmanji procenat neiskokanog zrna utvrđen je u zadnjem terminu berbe, kada je sadržaj vlage u zrnu bio ispod 18%.

Ključne reči: *kukuruz kokičar, sadržaj vlage u zrnu, zapremina kokičavosti, procenat neiskokanog zrna.*

INTRODUCTION

Production and consumption of popcorn is constantly increasing due to the fact that popcorn is profitable crop both concerning producers and merchants (*Silva et al., 2011; Moterele et al., 2012*). Its nutritive properties on the other hand are very attractive to consumers, which makes it very popular and nutritious snack food with excellent functional properties. Popcorn grain is a good source of fibre, calcium, iron, phosphorus, niacin, and it is low in calories when popped without oil (*Park et al., 2000; Paraginski et al., 2016*).

Popping volume is beside the yielding potential the most important trait of popcorn hybrids. Beside popping volume, the number of unpopped kernels is the most studied quality parameter of popcorn (*Ziegler, 2001*). High popping volume is correlated with desirable consumer attributes (*Ceylan and Karababa, 2002),* while unpopped kernels are an undesirable nuisance to consumers and unrealized profit to producers (*Sweley et al., 2012*). Several factors influence popping volume and the percentage of unpopped kernels, such as: moisture content, genotype, production and harvesting conditions, as well as the condition of processing and grain storage, and popping methods (*Gökmen, 2004; Allerd-Coyle et al., 2000; Karababa, 2006; Song et al., 1991*). Maximum of the popping volume could be achieved when the hybrid is harvested at full maturity, when moisture content is below 20%. *Hosney et al. (1983)* also stated that the best results of popping volume could be reached when grain moisture at harvest is between 15 – 18%. Biotic and abiotic stress factor during production, harvest and processing could lead to the decrease of the popping volume and also increase the percentage of unpopped kernels. Among those drought, frost, pests, diseases, mechanical kernel damaging are the most significant. Nevertheless, the most important factor influencing popping volume is the moisture content at the moment of popping. Researchers agree that the maximum of popping volume is produced at grain moisture ranging from 11.0% - 15.5% (*Allerd-Coyle et al., 2000; Shimoni et al., 2002; Pajić et al., 2006).* Moreover, grain moisture content of 14% is optimal, and produces highest popping volumes (*Gökmen, 2004; Srdić et al., 2015*). If the moisture content is lower, there is not enough pressure to produce expansion of the grain. On the other hand if the moisture content is higher it softens the pericarp, which also reduces popping volume *(Hosney et al., 1983).* Popping volume is also significantly influenced by genotype (*Srdić et al., 2015; Srdić et al., 2017*), popping method (*Gökmen, 2004),* and kernel size (*Pajić and Babić, 1991; Song and Eckhoff, 1994*). Differences among genotypes are significant and important, because mostly higher yielding hybrids produce lower popping volumes (*Srdić and Pajić, 2011; Pajić et al., 2012, Cabaral et al., 2016*). The way to overcome this problem

in breeding high yielding and hybrids that produce high popping volume is found in the research of *Amaral et al., (2016)*, where they introduced trait – expanded popcorn volume per ha PV, that could provide simultaneous gains in both traits. Regarding kernel size it is found that larger kernels produce lower popping volume because they contain a higher percentage of soft endosperm, which is not favourable for expansion (*Pajić and Babić, 1991*). The aim of this study was to observe the influence of grain moisture at harvest and grain moisture at the moment of popping in order to analyse their influences on popping volume and on the percentage of unpopped kernels. The study will also show weather there are differences among selected genotypes. Interaction of observed factors will also provide interesting information about how the grain moisture at harvest and at popping time influences popping volume and percentage of unpopped kernels.

MATERIAL AND METHOD

For this study four popcorn hybrids developed at Maize Research Institute Zemun Polje were selected: ZP 611k, ZP 616k, ZP 501k, and ZP 608k. Three hybrids are single cross hybrids, and only ZP 501k is a three way cross hybrid. Trial was set at the nursery field in Zemun Polje in 2015. Sowing was performed on 27th of April, and emergence was noticed on 6th of May. Each hybrid was sown in plots of 75 m^2, i.e. 20 rows with inter row distance of 0.75 m, with 20 plant per row, with the final stand of 57,142 plants/ha. Two rows were border rows. Standard cropping practices were applied during growing season. Inner rows were harvested manually in three terms, six rows for each. The first term was when grain moisture was above 25%, the second when moisture content was 25 – 20%, and the last when the moisture dropped below 18%. Moisture content was measured with small samples by Dickey-john GAK II moisture meter. Meteorological conditions in 2015 had significant impact on grain maturation, so all harvest terms were performed until the fourth week of September (Table 1). Shelling of samples was performed manually in order to avoid damaging the pericarp, which could increase the percentage of unpopped kernels and lower the popping volume.

Table 1. Meteorological conditions in 2015 and ten year average 2005 - 2014

Month	2015		2005-2014	
	Temperature (^{0}C)	Precipitation (mm)	Temperature (^{0}C)	Precipitation (mm)
April	12.9	19.7	14.2	39.4
May	19.1	97.8	18.3	69.1
June	22.1	31.1	21.9	83.4
July	26.4	7.2	23.6	55.6
August	25.7	56.0	23.6	54.6
September	20.2	73.6	18.9	44.6

Each sample of the four hybrids, from three harvests was tested at six moisture contents (10%, 12%, 14%, 16%, 18%, and 20%). Initial moisture content was between 16.5 – 28%, depending on the harvest term. Samples that had moisture content above desired were dried by natural convection at room temperature, until the correct moisture content was obtained. Samples with lower moisture content than wanted were rewetted with distilled water using sprayer. They were kept in the refrigerator at 5 ^{0}C in closed fabric bags, inverted and shaken daily in order to distribute moisture evenly throughout the sample. The moisture was checked daily.

Popping volume (PV) was analysed by the standard procedure (MWVT- Metric Weight Volume Test), using the apparatus Cretors 2300w – Official Metric Wight Volume Tester, Creators which performs popping of kernels with oil. Popping volume is presented by the volume of popped kernel (cm^3) per weight of the unpopped - fresh kernel (g). A standard sample was 250g and it was popped in three replications to obtain results of popping volume. Unpopped kernel weight was measured and it was turned into percentage of unpopped kernels.

Data were analysed by three-way analysis of variance (ANOVA) and the treatment means were compared using Fisher's least significant test – LSD ($p<0.05$).

RESULTS AND DISCUSSION

Popping volume and percentage of unpopped kernels were significantly influenced by the genotype, what was also found by others (*Soylu and Tekkanat, 2007; Srdić et al., 2017*). Other two factors (moisture content at harvest and moisture content at popping), as well as all interactions had also significant influence on these two traits (Table 2).

Table 2. ANOVA and mean squares for popping volume, and % of unpopped kernels of four ZP maize hybrids

Sources of variance	Degrees of freedom	Mean Square	
		Popping volume	percentage of unpopped kernels
Replication	2	5.16	2.44
Genotype (A)	3	429.27**	1060.16**
Moisture content at harvest (B)	2	298.74**	727.65**
A x B	6	89.42**	53.81**
Moisture content at popping (C)	5	3370.24**	2661.60**
A x C	15	31.46**	164.43**
B x C	10	45.534**	319.58**
A x B x C	30	25.60**	72.79**
Error	142	5.10	4.70

*** significant at the 0.01 probability level*

Hybrid with the highest average popping volume was ZP 608k (22.32 cm^3/g), while the lowest popping volume produced hybrid ZP 501k (15.67 cm^3/g). Among each of the tested hybrids significant differences were found (Table 3). Hybrid ZP 608k had very high popping volume in all treatments. At the optimal grain moisture of 14% its popping volume was up to 41.33 cm^3/g. Even at less favourable grain moistures this hybrid mostly had higher popping volumes than other three. On the other hand ZP 501k had lowest popping volumes at all grain moistures. Even at 14% moisture content its popping volume was below 28.00 cm^3/g which is also considered very low and unsatisfactory popping volume. Average popping volume according to the grain moisture at harvest ranged from 17.65 cm^3/g when grain moisture was 20 – 25%, up to 21.48 cm^3/g when harvest was performed with the grain moisture below 18%. Previous studies also found significant differences among genotypes concerning popping volume (*Srdić et al., 2015*), and dependence of popping volume on the percentage of grain moisture (*Srdić et al., 2017; Gökmen, 2004*). In the study of *Shimoni et al. (2002)*, it was found that popping volume ranged from 15.8 ml/g up to 47.9 ml/g depending on the moisture content at popping time, which ranged from 6.69 to 16.52%.

All four hybrids significantly differed concerning the trait percentage of unpopped kernels. Significant differences among another set of hybrids was also found in previous study (*Srdić et al., 2017*). Hybrid ZP 608k also showed best performances, i.e. 3.30% of unpopped kernels on average. Percentage of unpopped kernels for this hybrid dropped with the lowering of moisture

content at harvest. It was the highest at first harvest term (4.74%), while at the last harvest term it was only 1.62%. Beside this hybrid, ZP 616k at harvest moisture content below 18% had even lower percentage of unpopped kernels of 0.44% (Table 4).

Table 3. Average estimates and LSD for popping volume of four ZP maize hybrids (cm^3/g)

percentage of moisture at harvest	percentage of moisture at popping	ZP 611k	ZP 616k	ZP 501k	ZP 608k	
> 25%	20	5.83	4.50	6.00	7.17	
	18	10.83	4.17	6.67	13.33	
	16	18.3	19.00	12.83	22.83	
	14	35.17	35.67	27.33	41.33	
	12	28.00	30.67	22.33	31.17	
	10	13.17	14.33	12.67	17.67	
	average	18.55	18.06	14.64	22.25	**18.38 b**
20-25%	20	13.83	4.17	5.50	5.67	
	18	11.33	7.33	9.67	11.00	
	16	13.33	15.67	15.17	18.67	
	14	29.67	29.33	27.83	38.33	
	12	26.33	26.67	22.00	30.33	
	10	15.33	16.17	11.67	18.67	
	average	18.30	16.56	15.31	20.44	**17.65 b**
< 18%	20	6.00	18.33	13.83	12.00	
	18	8.00	24.83	8.33	16.67	
	16	21.67	30.00	19.33	24.17	
	14	34.17	37.83	26.00	40.00	
	12	26.33	28.83	21.83	33.83	
	10	15.00	16.67	13.00	19.00	
	average	18.53	26.08	17.05	24.28	**21.48 a**
	average	**18.46c**	**20.23b**	**15.67d**	**22.32**	

Means followed by the same letter are not significantly different according to $LSD_{0.05}$

Hybrid ZP 501k likewise in the popping volume had poorest results. Its percentage of unpopped kernels was the highest of all hybrids in this research (13.79% on average). This hybrid is therefore indicated as the least favourable concerning quality parameters. Mostly all hybrids had lowest percentage of unpopped kernels at 14% moisture content at popping, while some exceptions to this is found in hybrid ZP 608k which had even lower percentage at lower moisture contents at popping (12% and 10%). In the study of *Sweley et al., (2012)*, percentage of unpopped kernels ranged from 10.1 – 12.5% depending on the genotype, which they indicated as consumers acceptable (*Quinn et al., 2005*). Our research is also in accordance with *Gökmen, 2004*, who investigate percentage of unpoped kernel (PUK) in dependence of moisture content at popping time, ranging from 8 -20%. Lowest PUK in their research was also found at 14% moisture content and highest at 20%.

As shown on the Figure 1. the best popping performances are produced at 14 % moisture content at popping. Average popping volume was highest at that moment (33.56 cm^3/g), while it dropped with the increase or decrease of the moisture content at popping. The lowest average popping volume of all four hybrids was at 20 % moisture content (8.57 cm^3/g). Nevertheless all other average popping volumes with the exception at 14 % moisture content are considered unsatisfactory from the commercial point of view, because popcorn is also sold by the popping volume (*Shimoni et al., 2002*).

The other analysed trait the % of unpopped kernels is in reverse proportion to the popping volume (Figure 1). The more kernels succeed to develop into flake, the more commercial value of the final product is. So this is very important parameter of popcorn hybrids. At optimal moisture content of 14%, the lowest percentage of unpopped kernels was, only 0.62%. This percentage slowly increased with the decrease of moisture content to 12 and 10% (1.13 and 3.17%, respectively), while this was more pronounced when the moisture content increased to 16, 18 and 20% (5.91, 15.07 and 21.79, respectively). This leads to the conclusion that higher moisture content at popping is less favourable for the quality of popcorn, than to the same extent less moisture content of kernels at popping. When popped at 12% moisture content average popping volume was 27.36 cm^3/g, with only 0.62% of unpopped kernels, while at 16% moisture content average popping volume dropped to 19.25 cm^3/g, with 5.92% of unpopped kernels.

Table 4. Average estimates and LSD for % of unpopped kernels of four ZP maize hybrids (%)

percentage of moisture at harvest	percentage of moisture at popping	ZP 611k	ZP 616k	ZP 501k	ZP 608k	
> 25%	20	31.15	20.11	40.76	17.09	
	18	19.95	39.10	21.87	6.72	
	16	11.60	4.27	15.93	2.69	
	14	0.73	0.28	0.81	1.03	
	12	0.96	0.24	3.28	0.47	
	10	2.92	0.93	10.21	0.42	
	average	11.22	10.82	15.48	4.74	**10.56 a**
20-25%	20	35.00	26.47	48.60	11.27	
	18	8.35	14.20	23.37	6.18	
	16	6.44	3.65	9.94	2.58	
	14	0.33	0.16	1.21	0.29	
	12	0.63	0.20	3.07	0.27	
	10	0.65	0.24	9.30	0.58	
	average	8.57	7.49	15.91	3.53	**8.87 b**
< 18%	20	14.74	0.69	11.46	4.17	
	18	13.49	0.42	25.53	1.70	
	16	2.84	0.32	8.16	2.53	
	14	0.58	0.14	1.34	0.51	
	12	0.58	0.22	3.20	0.45	
	10	1.41	0.87	10.15	0.36	
	average	5.61	0.44	9.97	1.62	**4.41 c**
	average	**8.46 b**	**6.25 c**	**13.79 a**	**3.30 d**	

Means followed by the same letter are not significantly different according to $LSD_{0.05}$

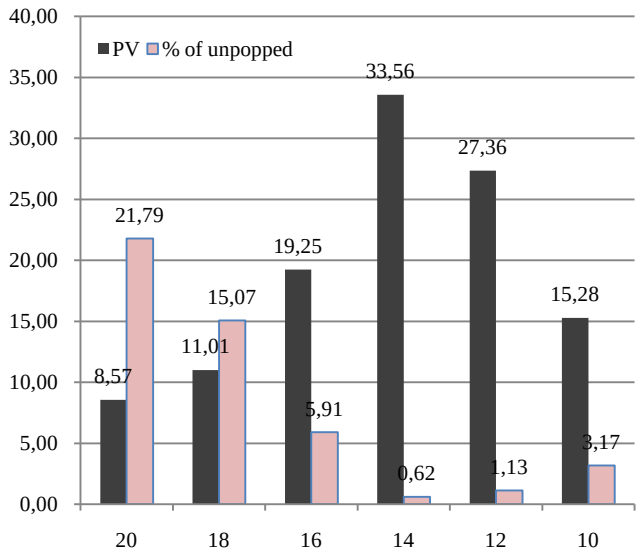

Fig. 1 Average estimates of popping volume and percentage of unpopped kernels depending on the moisture content at popping time

CONCLUSION

Popping volume and percentage of unpopped kernels are very important traits which determine the quality of popcorn. Commercial value of popcorn increases with the higher popping volume, and the lower percentage of unpopped kernels. Therefore it is confirmed in this research that moisture content of 14% at popping is the best moment for popping. At this moisture content all hybrids produced highest popping volumes and lowest percentage of unpopped kernels, which on average were 33.56 cm^3/g and 0.62% of unpopped kernels. With the increase or decrease of moisture content popping volume dropped and percentage of unpopped kernels increased. Among analysed hybrids significant differences were found both concerning popping volume and percentage of unpopped kernels. Best performances were noticed for ZP 608k, while the poorest results presented ZP 501k. Concerning the moment of harvest i.e. moisture content at harvest, best results were obtained at last harvest term when moisture content was below 18%. Average popping volume was highest at that point (21.48 cm^3/g), and average percentage of unpopped kernels was lowest (4.41%). Therefore, for the best quality results of popcorn final product – the flake, its harvest should be performed when the moisture content drops below 18%.

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REFERENCES

Allerd-Coyle,T.A., Toma, R.B., Reiboldt, W., Thaku, M. (2000). Effects of moisture content, hybrid variety, kernel size and microwave wattage on the expansion volume of microwave popcorn. International Journal of Food Sciences and Nutrition, 51, 389-394.

Amaral, A.T., dos Santos, A., Gerhardt, I.F.S., Kurosawa, R.N.F., Moreira, N.F., Pereira, M.G., Gravina G. de A., de L. Silva F.H. (2016). Proposal of super trait for the optimum selection of popcorn progenies based on path analysis. Genetics and Molecular Research, 15 (4), gmr15049309, 1-9, DOI http://dx.doi.org/10.4238/gmr15049309.

Cabaral, P.D.S., Amaral Junior, A.T., Freitas, I.L.J, Ribeiro, R.M. (2016). Cause and effect of quantitative characteristics on grain expansion capacity in popcorn.Rev. Ciênc. Agron., 47 (1), 108-117. http://dx.doi.org/10.5935/1806-6690.20160013.

Ceylan, M., Karabab E. (2002). Comparison of sensory properties of popcorn from various types and sizes of kernel. Journal of the Science of Food and Agriculture, 82,127-133.

Gökmen, S. (2004). Effects of moisture content and popping method on popping characteristics of popcorn. Journal of Food Engineering, 65, 357-362.

Hosney, R.C., Zeleznak, K., Abdelrahman, A. (1983). Mechanism of popcorn popping. J. Cereal Sci. 1, 43-52.

Karabab, E. (2006). Physical properties of popcorn kernels. Journal of Food Engineering, 72, 100-107.

Moterele, L.M., A.L. Braccini, C.A. Scapim, R.J.B. Pinto, L.S.A. Gonçalves, R. Rodrigues (2012): Combining ability of popcorn lines for seed quality and agronomic traits. Euphytica, 185: 337-347.

Quinn, Sr P.V., Hong, D.C., Both, J.A. (2005). Increasing the size of a piece of popcorn. Physica A 353, 637-648.

Pajić, Z., Babić, M. (1991). Interrelation of popping volume and some agronomic characteristics in popcorn hybrids. Genetika, 23, 137-144.

Pajić, Z., Srdić J., Filipović, M. (2006). Odnos rodnosti i zapremine kokičavosti hibrida kukuruza kokičara (Zea mays L. everta).Selekcija i semenarstvo, 12, 81-83.

Pajić, Z., Srdić, J., Todorović, G., Babić, M., Radosavljević, M. (2012). Odnosprinosazrna i drugihvažnih osobina kukuruza kokičara (Zea mazs L. everta). Selekcija i semenarstvo, 18, 27-32.

Paraginski, R.T., Ziegler, V., Ferreira, D.C., Coussi, R., Gutoski, L.C., da Rosa Zavareze, E., Elias, M.C. (2016). Properties of popcorn starch expanded in microwave, with and without the presence of vegetable oil. Journal of Food Processing and Preservation, doi:10.1111/jfpp.13142, in press.

Park, D., Allen, K.G.D., Stermitz, F.R., Maga, J.A., (2000). Chemical composition and physical characteristics of unpopped popcorn hybrids. J. Food Compos. Anal., 13, 921-934.

Shimoni, E., E.M. Dirks, T.P. Labuza (2002). The relationship between final popped volume of popcorn and thermal-physical parameters.Lebensmittel-Wissenschaft und Technolgie, 35,93-98.

Silva, V.Q.R., A.T. Amaral Junior, L.S.A. Gonçalves, S.P. Freitas Junior, R.M. Ribeiro (2011). Heterotic parameterizations of crosses between tropical and temperate lines of popcorn. Acta Scientarium Agronomy, 33:243-249.

Song, A., S.R. Eckhoff, M. Paulsen, J.B. Litchfield (1991). Effects of kernel size and genotype on popcorn popping volume and number of unpoppedn kernels. Cereal Chemistry, 68, 464-467.

Song, A., S.R. Eckhoff (1994). Optimum popping moisture content for popcorn kernels of different sizes. Cereal Chemistry, 71, 458-460.

Soylu, S. and Tekkanat, A. (2007). Interaction amongst kernel properties and expansion volume in various popcorn genotypes. Journal of Food Engineering, 8, 336-341.

Srdić, J., Pajić, Z. (2011). Variability of yield and kernel quality parameters of pocorn hybrids (Zea mays L. everta). Journal on Processing and Energy in Agriculture 15, 84-86.

Srdić, J., Z. Pajić, M. Filipović, M. Sečanski (2015). The influence of moisture content of grain on popping volume of popcorn hybrids. Journal on Processing and Energy in Agriculture, 19 (1): 24-26.

Srdić, J., M. Milašinović-Šeremešić, M. Radosavljević, N. Kravić, V. Babić (2017). Evaluation of agronomic and sensory characteristics of popcorn kernel. Journal on Processing and Energy in Agriculture, 21 (4): 185-187.

Sweley, J.C., Rose, D.J., Jackson, D.S., (2012). Hybrid and environment effect on popcorn kernel physiochemical properties and their relationship to microwave popping performance. J. Cereal Sci., 55, 188-194. http://dx.doi.org/10.1016/j.jcs.2011.11.006

Ziegler, K.E., 2001. Popcorn. In: Hallauer, A. (Ed.), Specialty Corn. CRC Press, Boca Raton, FL, pp. 199-234.

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