AgroLife Scientific Journal - Volume 9, Number 2, 2020
ISSN 2285-5718; ISSN CD-ROM 2285-5726; ISSN ONLINE 2286-0126; ISSN-L 2285-5718

STUDY OF BUCKWHEAT COLLECTION SUITABLE FOR SUMMER SOWING

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Abstract

Evaluation of the buckwheat collection and elaboration of varietal models for summer–autumn growth period was carried out in 2015-2017 in the North-Eastern Forest-Steppe area of Ukraine. The conditions for secondary (summer) crops were used as an analyzing background. On the basis of a species collection of buckwheat (Fagopyrum esculentum Moench.) represented by 124 samples, the working collection of 35 ones was formed. These samples are characterized by vegetation duration range of 70-85 days and yield level of 1.8-5.6 g/plant and they are potentially suitable for summer sowing. Depending on the reaction of plants to the analyzing background, the differentiation of the working collection into clusters was carried out, with the predominance of long-day (14%), photoneutrality (46%) and short-day (40%) characteristics. The groups with vegetative and generative mechanisms of indicator realization and their combination among short-term samples were selected. Models of siderat and grain directions with potential yield level of 5.3-6.2 t/ha of dry matter and 2.8-3.6 t/ha of grain have been identified and created.

Key words*: buckwheat, short-day indicator, yield.*

INTRODUCTION

Buckwheat is an important cereal crop, traditional for Ukraine, in a number of Eastern and Central Europe countries and Far Eastern region (Bastida, 2019). The stable feature of recent decades is the reduction of areas under buckwheat in the main regions of its cultivation. The main reason is the specific requirements for growth conditions, low and unstable yields and limited market for the use of crop products.

Recently interest in buckwheat crop has been renewed. The basis of this trend is a change in approaches to the daily diet in favor of products with a balanced chemical composition. Identification of specific (gluten-free, restorative, sports etc.) nutrition trends is equally important (Ahmed et al., 2013). This has led to the expansion of buckwheat research as a source for human consumption (Skrabanja et al., 2004; Small, 2017; Bastida et al., 2019) as well as a forage compound for animal feeding (Christa & Soral-Smietana, 2008).

Study of metabolism and synthesis of flavonoids in buckwheat seeds causes special interest in this area (Li et al., 2019). Unconventional area of research is the study of the taxonomy of the *Fagopyrum* species based on chemical composition of grain (Zhang et al., 2017; Fesenko & Fesenko, 2019), color of flowers (Zaika et al., 2019), and genome coding sequences (Yasui et al., 2016; Shi et al., 2017).

The prospect of these studies is determined by the differences in the domestication conditions of crop and by low level of breeding restructuring of modern varieties. This leads to a high heterogeneity of the genetic material of modern buckwheat crop (Tryhub & Burdyha, 2015; Trygub & Liashenko, 2017). Applied breeding and technological studies based on the specific biological characteristics of the *Fagopyrum* species are less common and need more attention. Mukasa et al. (2010) achieved significant results in this area of research, which received a 10% yield increase in F_1 due to the use of the heterosis phenomenon. The

technique is based on the use of the self-compatibility gene obtained with *Fagopyrum homotropicum Ohnishi*. Koyama et al. (2019) analyzed the possibility of increasing yields by optimizing plant architectonics. The authors identified the number of critical phases of plant development that require technological control and determine approaches to developing the variety model for certain agroclimatic conditions (Siracusa et al., 2017; Koyama et al., 2019).

Another promising area for the breeding improvement of the modern buckwheat crop is the use of the photoperiodism phenomenon. Biological basics of it are analyzed in detail in many studies (Petr & Hradecka, 2003; Hara & Ohsawa, 2013; Chrungoo et al., 2016; Saad et al., 2019). However, this phenomenon so far has not gained wide practical implementation in crop improving. (Fesenko & Fesenko, 2019).

The persistent tendency to climate warming has led to the technological possibility of buckwheat cultivation as secondary (summer) crop in areas with a sufficient level of humidity. In Ukraine, these areas are located in the northern Forest-Steppe and Polissya. The practice of expanding this type of crops shows significant differences between conditions of spring-summer growth period and the conditions of summer-autumn growth period in summer sowing.

The actual yield of buckwheat crop with traditional varieties is at the level of 0.55-0.65 t/ha. This situation needs the creation of specialized varieties adapted to the conditions of short day and higher level of warmth supply for juvenile developmental phases.

The main task of the research was to study the buckwheat collection for the selection of samples suitable for cultivation under summer sowing in the northern Forest-Steppe of Ukraine.

MATERIALS AND METHODS

The studies were carried out for 2015-2017 at the Institute of Agriculture of the North-East of NAAS of Ukraine and Sumy National Agrarian University. The soil of the research plots is typical, low-humus chernozem, slightly leached, coarse-dusty, on medium-loamy loess. Main characteristics of the soil are: humus content - 4.1%, pH - 6.3, the content of mobile forms of phosphorus - 11.3 mg/100 g, the content of exchangable potassium - 9.2 mg/100 g, the content of lightly hydrolyzed nitrogen according to Cornfield - 11.2 mg/100 g. The climate of zone is continental, with unevenly distributed of precipitation and medium air humidity.

The weather conditions of the growth periods of 2015, 2016, 2017 were characterized by the following indicators:

- Sum of temperatures: 2502, 2487, 2332°C;
- Precipitation: 278, 382, 157 mm;
- Hydrothermal coefficient (GTC): 1.11; 1.5; 0.67.

The average buckwheat yield in the region for these years was: 1.34; 1.39 and 1.15 t/ha.

The wide range of weather conditions provided the opportunity to display and study the basic characteristics of the samples, efficient selection of breeding traits and the selection of valuable sources with characteristics of adaptability to the conditions of summer sowing.

The research material was the species collection, represented by 124 samples of buckwheat of *Fagopyrum esculentum* Moench. of different ecological and geographical origin. The national standards of buckwheat – Krupynka variety (determinant morphotype) and Ukrayinka variety - were used as testers.

Testing of selection samples was carried out on the following variants:

- Traditional sowing (spring-summer growth period). Cultivation conditions: spring barley as previous crop in rotation, the basic tillage was autumn plowing. Fertilizer application ($N_{30}P_{30}K_{30}$) + pre-sowing cultivation was made in spring. Buckwheat samples was sown with breeding seeder on 10-12 of May, with row spacing of 15 cm and a sowing rate of 3.0 ml/ha. Term of harvesting was 10-15 of July.
- Summer sowing or secondary crop (summer-autumn growth period). It was analyzing background. Cultivation conditions: pre-crop was winter wheat (harvested on 5-8 of July). Disking and rolling were used as soil tillage. Sowing was done on 6-9 of July, with breeding seeder, with row spacing of 15 cm and sowing rate of 3.0 ml/ha. Term of harvesting was 14-18 of September.

The placement of plots was systematic, in three replications. The accounting area of one plot is 1.35 m^2.

In our research planning and conducting of experiments, the accounting of plant parameters, the level of yield and the quality of grain were carried out in accordance with "Method of state variety testing of agricultural crops" (2001). The evaluation of the buckwheat collection and hybrid material by morphological, technological characteristics and duration of vegetation was carried out in accordance with Tryhub et al. (2013).

Data analysis and mathematical calculations were done with the help of the license packages "MS Office" and "Statistica 6.0". The test of least significant differences (LSD) was applied to compare calculated averages of indicators (Steel and Torrie, 1997).

Considering the difference in the expected "cluster volumes" and the use of different categories of indicators for grouping, the median (centroid) method was chosen with an cluster distance estimation in "percent of disagreement".

RESULTS AND DISCUSSIONS

It has been determined that the conditions of summer sowing in the North-Eastern Forest-Steppe were characterized by higher level of warm supply in juvenile phases of plant development (compared to spring sowing term). Thus, the indicator of the sum of average daily temperatures of the period of "seedlings–flowering" was 720°C (½ of the total indicator of the sum of temperatures during the growing season).At the same time the value of this indicator under traditional cultivation was 350-400 (less than 1/4). The beginning of generative phases of plant development was observed at the day length of 14-13 hours, while under the conditions of spring-summer growth period at 15-16 hours duration. Under summer sowing the precipitation for the growing season was 177 mm (19% lower than under traditional sowing conditions) and average air humidity was 18% lower.

The complex factors of summer-autumn vegetation gave the reasons to search for genotypes with short-day characteristics. Variety samples should be marked by the accelerated passage of the period of "seedlings-flowering" under conditions of shorter day length and positive reaction to the higher level of warm supply of juvenile phases of plant development.

Characteristics of the buckwheat species collection

The targeted creation of varieties focused on specific conditions of cultivation, there is a threat of narrowing their genetic basis. In order to reduce such phenomenon in the breeding work was involved the maximum number of collection samples of different origin, the characteristics of them were correspond to the conditions of the research area. On the basis of characteristics, the species collection of 124 buckwheat samples of *Fagopyrum esculentum* Moench. was formed. The collection included 94 specimens of the determinant (normal) type and 30 specimens of the determinant type (Figure 1).

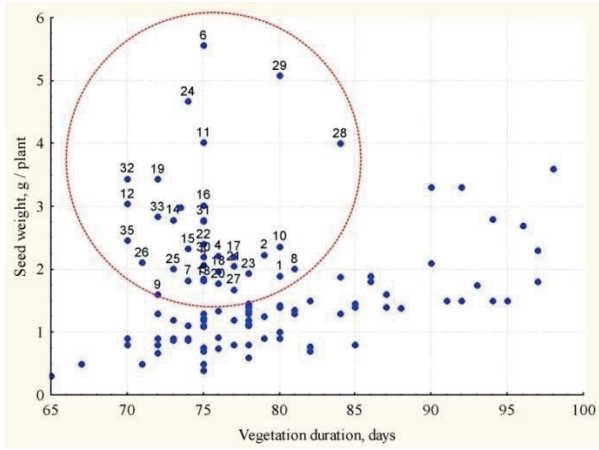

Figure 1. Sample distribution of the buckwheat species collection depending on productivity and duration of vegetation in the conditions of analyzing background (2015-2017)

**figures indicate the samples included in the working collection*

The structure of collection corresponded to the differentiation of modern buckwheat crop in the conditions of the Forest-Steppe zone of the Eurasian continent. On the basis of such indicators as growth period duration, yield capacity and yield quality (mass of 1000 seeds), the working collection was formed. It included 35 breeding samples and 2 variety-standards.

The working collection was created with some constriction of the genetic basis of the species

collection: it did not included ultra-early samples with low-productivity and growth period less than 70 days; samples with a productivity less than 1.5 g/plant, and late-matured samples with growth period more than 85 days.
Created on the basis of the passport collection, it consisted of 17 national samples origin, in particular: UC0101979, UC0101065, UC0101059, UC0101058, UC0101008, UC0100653, UC0100658, UC0101129, UC0102195, UC0100153, UC0100987, UC0100988, UC0100267, UC0100340, UC0101990, UC0101993, UC0101925,18 samples of foreign origin, including 12 from different administrative and geographical regions of the Russian Federation (UC0100066, UC0101116, UC0100045, UC0101868, UC0100990, UC0100130, UC0100002, UC0101195, UC0101093, UC0101871, UC0102183, UC0101195), 3 samples from the Republic of Belarus (UC0100991, UC0100367, UC0100362), 1 sample from Kazakhstan (UC0101698), 1 sample from Japan (UC010177) and 1 sample from Poland (UC0101977).
The samples were ecologically and geographically distant. The most interesting genotypes among them were with such characteristics as: determinism, pronounced architectonics of plant habitus (UC0101975, UC0101993), narrow-leaved (UC0101977), limited branching (UC0100267), homostylus (UC0100362), drought-resistance and red-flowering (UC0101871), large-fruited (UC0101698).
The study of the working collection was conducted under the conditions of traditional sowing and analyzing background. The average values, range and level of variation of the main breeding-controlled traits were determined (Table 1).

Table 1. Characteristics of a working collection by parameters of vegetative and generative plant development (2015-2017)

Indicators	Traditional sowing				Summer sowing (analyzing background)			
	X	min	max	Cv, %	X	min	max	Cv, %
Seedlings-flowering, days	25.2	21.0	35.0	13.8	24.0	20.0	33.0	12.5
Flowering-maturing, days	52.0	42.0	65.0	20.0	52.6	42.0	67.0	24.1
Seedlings-maturing, days	77.2	70.0	80.0	8.8	76.6	70.0	90.0	9.8
High of plant, cm	117.0	92.0	150.0	6.3	119.0	105.0	158.0	6.0
Number of notes, pcs.	12.5	8.8	18.0	4.9	12.5	9.4	7.2	5.9
Number of I-st order branches, pcs.	3.8	2.2	6.6	28.8	3.4	1.6	2.8	29.8
Area of leaves, cm^2	280.0	133.0	741.0	41.9	260.0	173.0	356.0	30.4
Weight of plant, g	9.4	3.2	18.3	43.3	9.1	3.5	19.7	42.4
Yield capacity (productivity), g/plant	2.45	0.71	6.32	33.6	2.01	0.64	4.12	25.5
Number of filled seeds, pcs.	100.0	10.6	353.4	32.3	91.5	27.8	210.4	25.0
Number of unfilled seeds, pcs.	120.0	22.6	259.0	43.9	136.0	37.4	261.0	32.1
Mass of 1000 seeds, g	24.5	16.7	34.0	10.0	24.6	18.3	32.8	13.7

It was determined that the conditions of the analyzing background increased the values in the following indicators: the duration of the "flowering-maturing" period, plant height, the number of unfilled seeds and the mass of 1000 seeds by 1.15; 1.71; 13.3 and 0.41%, respectively. Increase in the level of variability (Cv) was observed in the duration of "flowering-maturing" period (4.1%) and the mass of 1000 seeds (3.7%), which was due to the slight extension of the values range. As for other indicators, the increase in the mean values was due to the shift of the range and narrowing of its limits. Yield capacity and the number of filled seeds are important indicators of generative development. These parameters were characterized by decrease in the mean values in the secondary sowing conditions by 17.9 and 9.0%, respectively.

The structure of the working buckwheat collection by reaction to the day length

The reaction to the day duration is considered to be the complex ability of plant to adapt to environmental conditions. Comprehensive analysis of the working collection allowed to distinguish three clusters with predominance of long daytime indicator, photoneutrality and short daytime indicator (Figure 2).

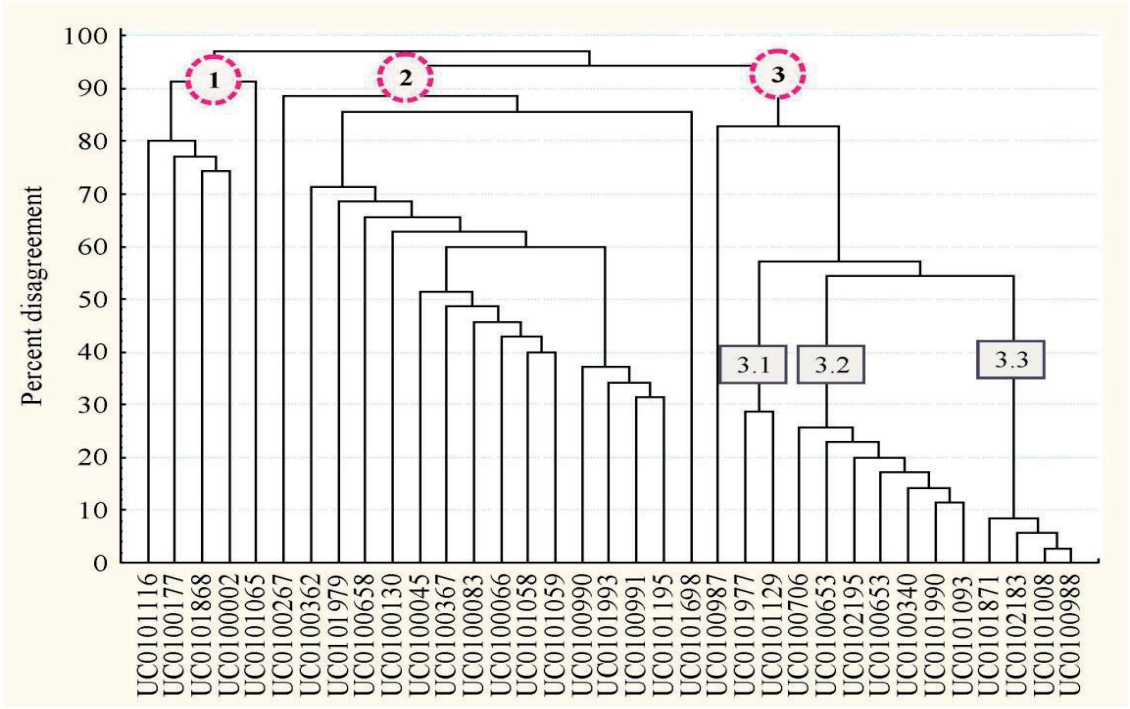

Figure 2. Dendrogram of sampe clustering of working collection by parameters of vegetative and generative development in the conditions of the analyzing background (2015-2017)

The long-day (1) cluster included 5 samples, or 14%. The clearest manifestation of long-day indicator was noted in sample of UC0101868. The duration of the "seedlings-flowering" period for it increased from 29 to 31 days (NIR0.05 = 2.0) with decreasing of plant productivity from 8.8 to 6.59 g. Samples of UC0101116, UC0100177 had the similar (but less clear) reaction on summer sowing.

The cluster of photoneutral samples (2) had 16 ones, or 46% of the total. The difference in the time of flowering phase in spring and summer crops did not exceed two days, and the difference in plant productivity did not exceed 0.5 g/plant (LSD $_{0.05}$ = 0.56). This cluster also included variety-standards.

The short-day predominance cluster (3) covered 40.5% of the samples; it was formed by UC0100653, UC0101008, UC0101129, UC0102195, UC0101977, UC0100706, UC0100153, UC0100987, UC0100988, UC0100340, UC0100801, UC0100801 ones. The most clear short-day characteristics were observed in the UC0101990 sample (Kvitneva variety): the length of the "seedlings-flowering" period decreased on average by 7 days. However, the decline in growth period duration was not accompanied by a decrease in productivity.

Differentiation of the cluster of short-day samples and mechanisms for the manifestation of the short-term indicator.

Statistically significant differences between plant indicators in buckwheat collection samples under traditional and summer sowing were previously determined: reduction of the "seedlings-flowering" period, increase in plant productivity under short-day conditions and different combinations of these characteristics. They became the basis for further differentiation of buckwheat samples within the short-day cluster. There were 3 groups of samples with different mechanism of manifestation of short-day indicators.

1. Group with a vegetative mechanism for the manifestation of short-day indicator (UC0101129, UC0101977 and UC0100987). In the conditions of summer sowing, the samples retained the productivity indicators (typical for traditional crops), however, they significantly reduced the duration of the "seedlings-end of vegetation" period.

2. Group with "generative" mechanism of manifestation of the short-day indicator (UC0101093, UC0101990, UC0100340, UC0102195, UC0100653, UC0100706 and UC0100153). In the conditions of summer sowing, the samples increased the productivity of the plants with stable indicators of the

"seedlings-flowering" length period and the total duration of the growing season.

3. Group with a combination of "vegetative" and "generative" mechanisms of manifestation of the short-day indicator (UC0101988, UC0101008, UC0102183 and UC0101871). Samples of this group in summer sowing increased the productivity of plants while reducing the total growing season.

Intra–group correlations between the plant productivity index (Wg) and the complex of indicators of their vegetative and generative development were determined to evaluate the features of yield formation in these groups and to determine possible directions of selection (Table 2).

The first group (with the vegetative mechanism of manifestation of the short-day indicator) was characterized by large number of negative correlations of plant productivity index (Wg) with the parameters of their vegetative development and individual productivity indicators. This is explained by increased level of plant branching, their height and small seeds.

Table 2. Group structure of productivity index (Wg) correlations of short-day buckwheat samples (2015-2017)

Indicators	Group 1	Group 2	Group 3
Duration of "seedlings-flowering" period (D_{se-fl}), days	-0.21	0.78	0.40
Duration of vegetation period (D), days	-0.31	0.25	0.04
Mass of 1000 seeds (W_{1000}), g	-0.31	0.62	0.52
Number of seeds per plant (N_{SE}), pcs.	0.77	0.78	0.56
Number of unfilled seeds (N_{S0}), pcs.	0.65	-0.07	-0.61
Number of inflorescences (N_{INF}), pcs.	0.53	0.45	0.16
Number of flowers (N_{FL}), pcs.	-0.16	0.18	0.26
Hight of plant (H), cm	-0.57	0.08	0.55
Number of nodes (Nnd), pcs.	-0.32	0.02	0.28
Number of branches of I order (B_1), pcs.	-0.22	0.23	0.02
Number of branches of II order (B_2), pcs.	0.39	0.25	0.04
Weight of plant (W), g	0.64	0.73	0.31
Number of leaves per plant (N_L), pcs.	0.59	0.66	0.11
Area of leaves (A), cm^2	0.50	0.27	0.23
Area of one leaf (A_l), cm^2	0.03	-0.38	0.52

The second group (the generative mechanism for the manifestation of the short–day indicator) was characterized by high level of correlation (r = 0.78) of the index (Wg) with the duration of the "seedlings–flowering" period. Significant positive correlations in the group were in terms of mass of 1000 seeds (r = 0.62) and number of seeds (r = 0.78). Like the first group, statistically significant correlations for Wp (r = 0.73) and N_L (r = 0.66) were retained.

Samples of the third group had significantly different pattern of plant productivity index correlations. First of all, it was related to the presence of significant negative correlation of the number of unfilled seeds (r = –0.61) and positive correlations of the productivity index with the height (r = 0.55), the area of one leaf (r = 0.52).

Based on the complex analysis of short-day sample group according to vegetation indicators under the conditions of analyzing background and characteristics evaluation of their productivity forming, two possible directions of selection were identified. They will be the basis for creating the source material of buckwheat varieties, oriented to the conditions of summer sowing. For clarity, the identified directions and expected values of key indicators were presented as models of future varieties (Table 3).

Table 3. Model indicators of buckwheat varieties for summer sowing in the area of the North-Eastern Forest-Steppe of Ukraine

Indicators	Models of variety for summer sowing		
	Siderat direction	Grain direction	
		Semi-intensive type	intensive type
Duration of growth period, days	more 80	70-80	70-75
Height of plant, cm /Development type	120-150/common	95-100/determinant or 100-120/common	70-100/determinant or 100-120/common
Leaf area, cm^2/plant	300-350	200-320	200-300
The potential of seed productivity, g/plant	1.0-3.0	2.0-5.0	2.7-5.5
Potential yield, g/ha	-	2.8-3.5	3.2-3.6
Biological yield, t/ha dry matter	5.3-6.2	-	-

The model of the siderat type was based on the use of the original sample forms: UC0101129, UC0101977 and UC0100987.

The presence of negative correlations between the plant productivity index and the number of vegetative development indicators showed the narrowed specialization of the future variety and more complex (compared to the traditional) scheme for its selection and further seed production.

Differentiation of grain direction models with the selection of intensive and semi-intensive variety types is less strict. It allows to make selection based on indicators of the seed number of and its size. Larger number of samples with these characteristics (7+4) indicates potentially high level of success of this breeding direction.

CONCLUSIONS

The completed stage of work confirmed the high level of heterogeneity of the modern buckwheat crop on the manifestation of photoperiodic characteristics and allowed to draw the following conclusions:

It was established that the conditions of buckwheat growth period under the summer sowing in the North-Eastern Forest-Steppe area were characterized by higher (+ 80%) level of warm supply of the juvenile phases of development, reduced duration of light day (minus 2 hours in the flowering phase and minus 4 hours in the seed filling phase), reduced precipitation (by 18%). Samples were identified and mechanisms of realization of short-day characteristics were determined.

"Vegetative" mechanism was manifested in the reduction (under the conditions of the analyzing background) of the duration of the period "seedlings-end of vegetation" without changing the productivity of plants, samples: UC0101129, UC0101977 and UC0100987.

"Generative" mechanism of implementation was to increase of values of seed productivity without changing the duration of their growing season, samples: UC0101093, UC0101990, UC0100340, UC0102195, UC0100653, UC0100706 and UC0100153.

The mechanism of combining the “vegetative” and “generative” directions for the implementation of the short-day trait was characterized by increase in plant productivity with a reduction in individual phases or the entire growth period, samples: UC0101988, UC0101008, UC0102183 and UC0101871.

According to the differentiation results of the group of short-day samples and group features of productivity formation we have proposed models of grain varieties (intensive and semi-intensive types) with a potential level of grain yield of 3.2-3.6; 2.8-3.5 t/ha and siderat varieties with 5.3-6.2 t/ha of dry matter.

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