PHOTOSYNTHETIC EFFICIENCY AS BASIS FOR YIELD FORMATION IN SUNFLOWER HYBRID NS-H-43 AND ITS PARENTAL LINES

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INTRODUCTION

The sunflower is characteristic for its high photosynthetic potential (El-Sharkawy et al., 1965), high growth rate (Warren Wilson, 1967), capacity to take up water from deep soil layers and to transport it through the vascular tissue (Black, 1979), and the heliotropic movement of leaves and head (Shell et al., 1974; Lang and Begg, 1979).

Differences among sunflower genotypes in photosynthetic efficiency may result in considerable differences in the yields of biomass and seed per plant and per unit area (Lloyd and Canvin, 1977).

Photosynthetic efficiency in the course of plant development, translocation, use, and accumulation of assimilates and energy accumulated in chemical bonds of certain organic compounds (photosynthates), especially at the time of seed setting and filling, are essential for correct understanding of the formation of the yields of biomass and seed per plant and per unit area. Therefore, the physiological factors may limit the formation of sunflower yields (McWilliam et al., 1974). Biomass and seed yields per sunflower plant are the result of a complex interaction involving a number of physiological processes (actions of solar energy, mineral nutrition, respiration, growth, etc.). It ensues that the productivity of sunflower plants cannot be increased by changing individual factors affecting it (Andreeva et al., 1980).

Our objective was to study the importance of the efficiency of solar energy conversion at the level of the plant (photosynthetic efficiency) and dry matter redistribution and accumulation in the course of plant growth and development as well as the importance of these parameters for the formation of seed and biomass yields in the sunflower hybrid NS-H-43 and its parental lines OCMS-22 and RHA-SNRF.

MATERIAL AND METHODS

The object of this study was the sunflower hybrid NS-H-43 and its parental components, OCMS-22 (female component) and RHA-SNRF (male component). Experiments were conducted under field conditions. The parental lines and the hybrid were sown in separate plots, in three rows, 12 plants in each row, in the arrangement 70 × 30 cm.

The efficiency of solar energy conversion at plant level (photosynthetic efficiency) was estimated from the ratio:

$$\frac{\textbf{chemical energy of dry matter (calorimetric readings)}}{\textbf{Energy of photosynthetically active radiation (PAR)}} \times 100$$

Total photosynthetically active radiation reaching the plot during the period of study was estimated from the meteorological data on the duration of insolation in the period May-October 1985 in the locality of Rimski Šančevi (Mihajlović and Acs, 1985; Katić and Djaković, 1978). NAR and LAI were assessed (Ćupina and Jocić, 1972) at the stages of budding, flowering and wax maturity. Photosynthetic efficiency (%) for the whole plant was assessed at the same stages. Also, we assessed photosynthetic efficiency (%) in individual plant parts.

RESULTS AND DISCUSSION

1. LAI and NAR in the parental lines OCMS-22 and RHA-SNRF and the hybrid NS-H-43

Table 1 shows the values of LAI in OCMS-22, RHA-SNRF and NS-H-43. In the lines, the LAI kept increasing from the stage of budding till flowering and then it went down to the stage of wax maturity. The values of NAR displayed a similar trend. In the hybrid, the LAI decreased from the stage of budding to wax maturity while the NAR increa-

Table 1

Leaf area index (LAI) (m^2/m^2) and net assimilation rate (NAR) $(g/m^2/d)$ in the course of development and yield (kg/m^2) of sunflower hybrid NS-H-43 and its parental lines OCMS-22 and RHA-SNRF

Genotype	LAI/NAR	Bud-ding	Flo-wering	Wax matu-rity	Yield
OCMS-22	LAI	1.83	2.30	1.51	3.380
	NAR	3.99	8.02	1.97	
RHA-SNRF	LAI	1.72	3.20	1.49	740
	NAR	4.23	7.72	3.60	
NS-H-43	LAI	2.25	5.43	6.85	4.720
	NAR	4.28	9.35	8.30	

sed from budding to flowering and decreased from flowering to wax maturity. It might be concluded that the hybrid's LAI is larger than necessary at the early stages of development. It is also evident that the hybrid surpasses the lines in the NAR at flowering and wax maturity, which is most probably related with the values of LAD from flowering to wax maturity.

Rawson and Constable (1980) found a correlation between the LAI at flowering and seed mass per plant ($r = 0.86$) in sunflower hybrids Suncross 51, Suncross 52, Hysun 30, Sunfola 68/2 and the variety VNIIMK. Rawson et al. (1980), found similar relationships. Some authors, e.g., Terbea et al. (1976) did not find correlations between the NAR and seed yield in parental lines and hybrid progenies. Merrien et al., 1984 (unpublished results) found significant correlations between the LAD and biomass yield per plant and the LAD and seed yield per plant, $r = 0.93$ and $r = 0.94$, respectively. Marijanac (1985) obtained $r = 0.22$ and $r = 0.35$ for the seed yield vs. LAD, respectively. According to Jocić (1974), there exists the highly significant correlation of $r = 0.93$ between the level of seed yield and LAI at flowering and the regression equation is $Y = 1{,}641 + 0.14$ LA (leaf area), indicating that each m^2 of leaf area brings the average increase in seed yield of 0.14 kg/ha. The partial coefficients of correlation also indicate a large dependence of seed yield on the LAI at flowering. There exists a significant correlation between the LAI at milk maturity and seed yield per hectare, the regression equation being linear, $Y = 1{,}575 + 0.21$ LA (leaf area).

Rawson et al. (1984) found a correlation between the number of filled seeds on the head and the LAI at flowering ($R^2 = 0.75$).

2. Distribution and accumulation of dry matter in different parts of sunflower plant

Table 2 shows the dynamics of dry matter distribution in plant parts of the male line RHA-SNRF, the female line OCMS-22 and the hybrid NS-H-43. The results are given for different stages of development, expressed in grams per plant.

Table 2

Distribution of dry matter among plant organs at different stages of plant development for sunflower hybrid NS-H-43 and its parental lines OCMS-22 and RHA-SNRF (g per plant)

Genotype	Plant organ	Budding		Flowering		Wax maturity	
		g/plant	%	g/plant	%	g/plant	%
OCMS-22	Leaf	24.4	64	39.3	35	32.0	22
	Stem	13.1	34	55.6	48	50.0	36
	Head	0.7	2	20.6	17	16.0	42
Total :		38.2	100	115.5	100	143.0	100
RHA-SNRF	Leaf	22.9	60	54.7	44	31.5	17
	Stem	14.5	38	54.1	42	79.3	43
	Head	0.6	2	17.0	14	75.8	40
Total :		38.0	100	125.8	100	186.6	100
NS-H-43	Leaf	29.9	60	92.8	36	145.0	25
	Stem	19.9	39	123.1	46	170.0	29
	Head	0.4	1	45.9	18	265.6	46
Total :		50.2	100	261.8	100	581.0	100

The hybrid NS-H-43 had a significantly higher accumulation of dry matter per plant than the parental lines OCMS-22 and RHA-SNRF, at all stages of development. Also RHA-SNRF had a higher dry matter accumulation per plant than OCMS-22. The parental lines and the hybrid differed in the distribution of dry matter per plant parts at differed stages of development. The accumulation of dry matter in the leaves and stem of OCMS-22 lasted for 70 days ; after that period, the accumulation in the stem dropped rapidly. With RHA-SNRF and NS-H-43, the accumulation of dry matter in the leaves and stem lasted longer and a slowness at the end was quite low. The accumulation of dry matter in the head, i.e. seeds, increased gradually. The parental lines differed from the hybrid in the dynamics of dry matter accumulation in the head, i.e. the accumulation was considerably more intensive to the hybrid. It led us to assume that the redistribution of dry matter in favour of the head is one of the factors which bring about increased yields of seed and biomass per plant in hybrids as compared with their parents. Ćupina and Plesničar (1986) obtained similar results for the hybrid NS-H-27-RM and its parental lines.

There are numerous literature data dealing with the distribution of dry matter, i.e. assmilates, per sunflower plant parts at different stages of growth and development.

Terbea et al. (1976) found that hybrids are superior to their parental lines regarding the accumulation of dry matter per plant and per unit area. They also found that the accumulation is most intensive in the leaves at the beginning of the season. After the stage of budding, the major portion of dry matter accumulates in the stem and later on in the seeds. The same authors point out that the growth of the vegetative plant parts is more intensive at early stages which is related with sunflower hybrids.

Blanchet et al. (1982) applied the method of carbon balance which makes use of coefficients of glucose equivalents. They found these equivalents to be 1.2, 2.5 and 3 for carbohydrates, nitrogen compounds, and lipids, respectively, and drew the following conclusions on the redistribution of assimilates in sunflower plant :

— The stem and leaves reach maximum content of assimilates at the stage of flowering. After that, the content starts decreasing slowly, probably on account of assimilate transfer into the seed. The rate of redistribution, especially from the leaves, depends on genotype and environmental factors, water regime in first place.

— At the stage of flowering, the head has a small growth compared with the total plant growth.

— Seed filling results from photosynthesis as well as from transformation or redistribution of assimilates.

Chemical energy of dry matter production (in %) in individual plant parts of the parental lines RHA-SNRF (male) and OCMS-22 (female) and their hybrid NS-H-43 at different stages of growth and developments is presented in Figure 1. The percent of accumulated chemical energy in the leaf dropped sharply from the stage of budding to wax maturity. The percent in the stem grew to the stage of flowering and then went down to the end of the vegetative season. The percent of chemical energy in the head, i.e. seeds, increased gradually from the stage of budding to the end of physiological maturity.

3. Efficiency of solar energy conversion at plant level (efficiency of photosynthesis)

The indicator of the efficiency of solar energy conversion at plant level (efficiency of photosynthesis) used represents the ratio between the chemical energy of dry matter in whole plant or plant part (estimated experimentally by means of a calorimeter) and the energy of photosynthetically active radiation (PAR). Its value is expressed in percent (Kamel, 1959).

It should be pointed out that the parental lines were inferior to the hybrid in relation to the photosynthetic efficiency per plant (Figures 2 and 3), at all stages of plant development. Also, RHA-SNRF had a higher photosynthetic efficiency per plant than OCMS-22. In the parental lines as well as the hybrid, the photosynthetic activity per plant kept increasing from the stage of budding to wax maturity. It is in agreement with our previous findings (Ćupina et al., 1984). The hybrid had a significantly higher photosynthetic efficiency than the parental lines. Its values at the stages of flowering and wax maturity were 1.22 and 2.23%, respectively. It appears that the photosynthetic efficiency in the hybrid is related with the expression of heterosis, bringing increases in dry matter and seed yield per plant.

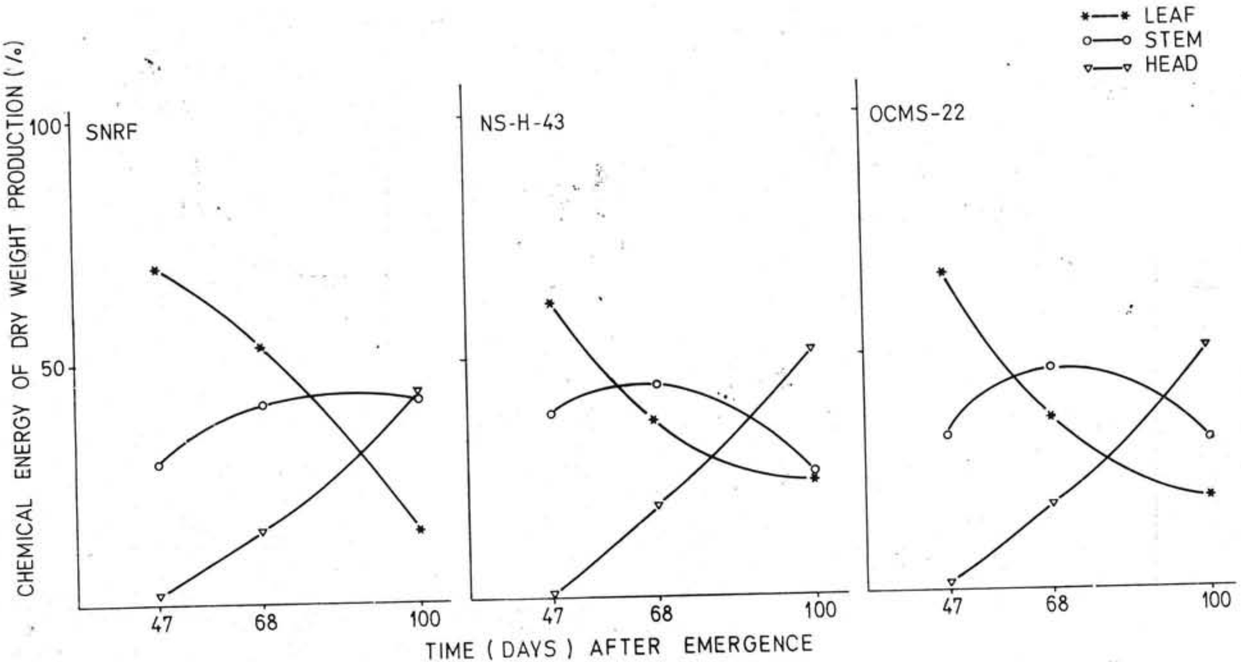

Fig. 1 — Distribution of accumulated chemical energy among leaf, stem and head for sunflower hybrid NS-H-43 and its parental lines in different stages of plant development

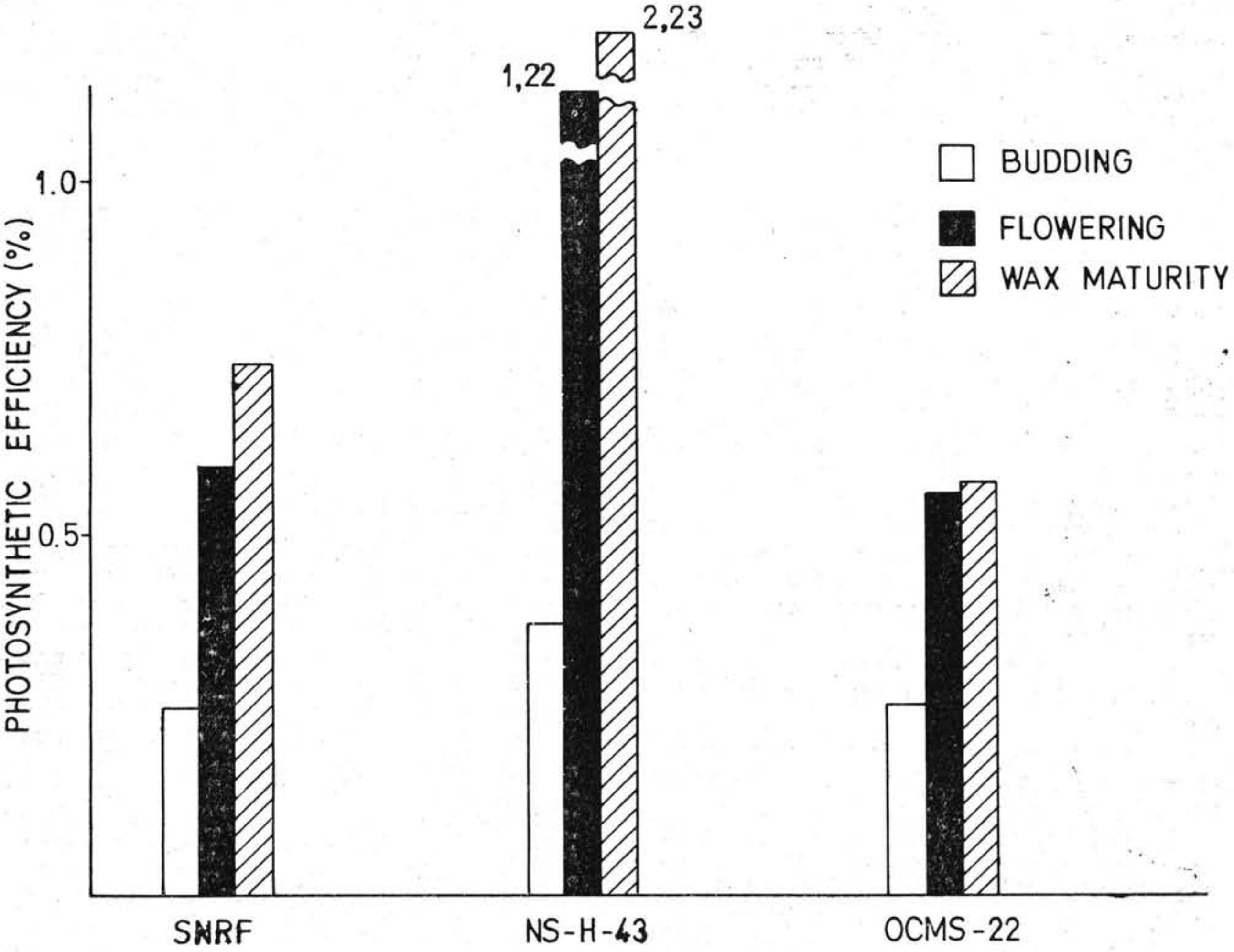

Fig. 2 — Photosynthetic efficiency per plant for sunflower hybrid NS-H-43 and its parental lines at the stage of budding, flowering and wax maturity

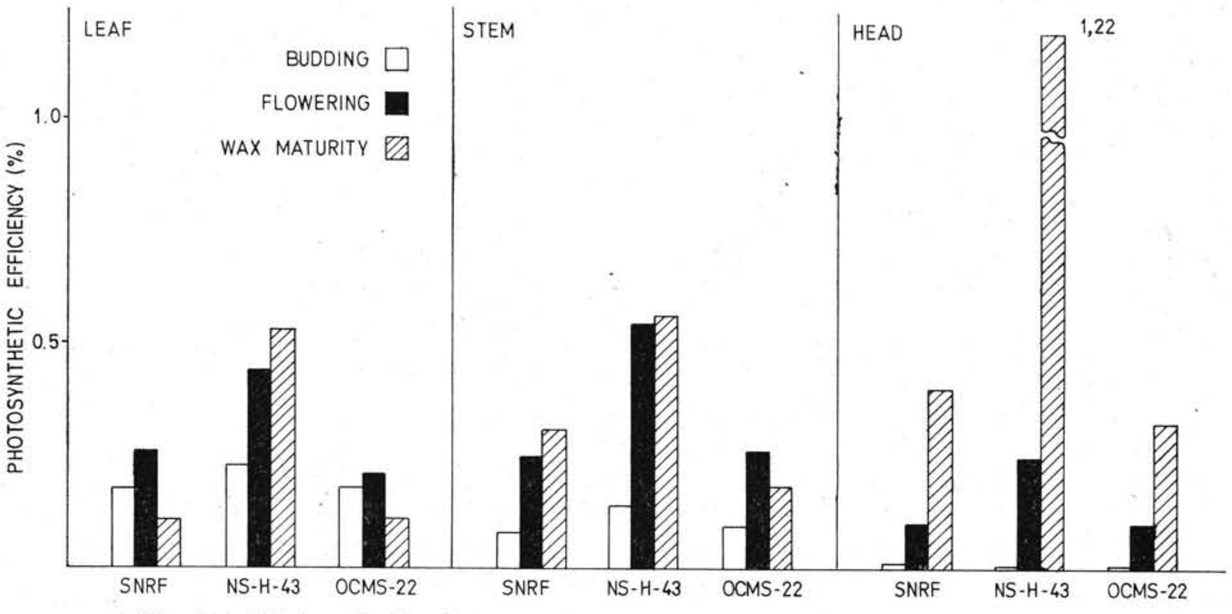

Fig. 3 — Photosynthetic efficiency per plant organ for sunflower hybrid NS-H-43 and its parental lines at different stages of plant development

Similar conclusions were drawn by Terbea et al. (1976).

Figure 3 shows the efficiency of PAR conversion in plant parts of the parental lines and the hybrid at different stages of growth and development. The photosynthetic efficiency of the leaf increased from the stage of budding to flowering and then decreased till wax maturity. In the hybrid, however, the photosynthetic efficiency of the leaf kept increasing to the stage of wax maturity. The photosynthetic efficiency of the stem followed a similar pattern. Regarding the photosynthetic efficiency of the head, it kept increasing from the stage of budding to wax maturity in the parental lines and the hybrid alike. The hybrid scored a significant increase in the efficiency at the stage of wax maturity on account of an increased portion of seeds in the head which utilized the energy of chemical bonds to form carbohydrates and oil, dominant componets in seed at that time.

The sunflower requires a certain amount of solar energy for its development. A reduction of light intensity by 40% lowered the yield of seed by 64%. A reduction of light intensity for 27 days at the stage of seed filling lowered the yield of seed by 36% (Robinson, 1978). The sunflower reaches photosynthetic saturation at relatively high light intensities (Robinson, 1978).

Many authors demonstrated a high positive correlation between the rates of absorption of light energy and synthesis of phytomass per sunflower plant and per unit area (Stern, 1962; Shibles and Weber, 1966; Fasheun and Dennett, 1982). According to Rawson et al. (1984), there exists a correlation between the total solar radiation absorbed and the synthesis of biomass per plant. Phytomass (g/pl) is linearly dependent on the total light energy absorbed from sowing to flowering (in MJ). The determination coefficient is $R^2 = 0.86$, indicating the absorbed energy as the main determinant in the phytomass production per sunflower plant. It is quite reasonable since the uptake of CO_2 depends directly on the absorption of light energy. However, seed yield per plant and solar radiation absorption are not invariably correlated because other factors too may affect the ratio of carbon distribution to seeds and the other plant parts. Solar radiation creates conditions for yield forming, but the development of seed buds and their subsequent performances are governed also by other ecological factors (e.g. temperature). According to Rawson et al. (1984) there are factors which are as important for seed forming in sunflower as CO_2 assimilation. They also found a partial correlation between the radiation absorbed from flowering to maturity and the number of filled seeds, estimating the determination coefficient between the two parameters at $R^2 = 0.90$.

CONCLUSIONS

The hybrid NS-H-43 had a significantly higher accumulation of dry matter per plant at all stages of growth and development than its parental lines, OCMS-22 (female line) and RHA-SNRF (male line).

The content of leaf dry matter in OCMS-22 increased to the stage of flowering, remaining at that level almost up to the stage of wax maturity. The dry matter content in the stem also increased till flowering but after that it dropped sharply. RHA-SNRF had a slightly more intensive increase of dry matter in the leaf and stem. NS-H-43 had the highest content of dry matter in the head.

The percent of chemical energy in the leaf went down rapidly from the stage of budding to wax maturity, especially in RHA-SNRF. The percent of chemical energy in the stem increased to the stage of flowering, decreasing towards wax maturity. The percent of chemical energy in the head, i.e. seeds, kept increasing up to the stage of wax maturity.

The photosynthetic efficiency per plant was significantly lower in the parental lines than in the hybrid at all stages of development. It appears that the photosynthetic efficiency of the hybrid is related with the expression of heterosis per plant, ultimately bringing increases in its biomass and seed yield.

The photosynthetic efficiency per individual plant parts varied in dependence on the stage of growth and development as well as among the parental lines and the hybrid.

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EFFICIENCE DE LA PHOTOSYNTHÈSE COMME BASE DE LA PRODUCTION DE L'HYBRIDE DE TOURNESOL NS-H-43 ET DE SES LIGNÉES PARENTALES

Résumé

L'efficience de la conversion de l'énergie solaire au niveau de la plante a été étudiée, ainsi que l'accumulation de la matière sèche le long de la croissance et du développement et l'importance de ces deux paramètres pour la formation du rendement en graines et de la biomasse.

L'hybride a montré une accumulation de matière sèche par plante significativement plus élevée pendant tous les stades de végétation, par rapport à ses lignées parentales : OCMS-22 (mère) et RHA-SNRF (père). La teneur en matière sèche des feuilles s'est accrue jusqu'à la floraison, restant presque au même niveau jusqu'à la maturité physiologique ; en revanche, celle de la tige a augmenté jusqu'à la floraison, mais elle a diminué rapidement après cette phase. L'hybride a eu une teneur bien plus élevée en matière sèche dans le capitule, par rapport aux lignées.

Le taux d'énergie chimique des feuilles s'est réduit rapidement à partir de la période de formation du bouton floral jusqu'à la maturité physiologique, tandis que celui de la tige a commencé sa diminution lors de la floraison. Le taux d'énergie chimique du capitule et des graines ont eu une croissance continuelle, jusqu'à la maturité physiologique.

L'efficience de la photosynthèse par plante a été de même significativement plus importante chez l'hybride qu'aux lignées parentales, pendant tous les stades de développement, suggérant l'influence du hétérosis même à cet égard. L'efficience de la photosynthèse par parties individuelles de la plante a enregistré une variation importante en dépendant du stade de croissance et de développement, ainsi que du génotype.

EFICACIA DE LA FOTOSINTESIS COMO BASE DE LA PRODUCCIÓN DEL HIBRIDO DE GIRASOL NS-H-43 Y DE SUS LINEAS PARENTALES

Resúmen

Se estudió la eficacia de la conversión de la energia solar al nivel de las plantas y la redistribución y acumulación de la sustancia seca durante el crecimento y el desarrollo, así como la importancia de estos parametros para formar la producción de semillas y biomasa.

El híbrido tuvo una acumulación de sustancia seca por planta significativamente más elevada en todos los estadios de vegetación comparando con sus líneas parentales : OCMS-22 (madre), RHA-SNRF (padre). El contenido de sustancia seca de las hojas creció hasta la fase de florecimiento, quedando casi al mismo nivel hasta la madurez fisiológica, en cambio él del tallo creció hasta el florecimiento, pero bajó rápidamente tras esta fase. El híbrido, frente a las líneas, tuvo un contenido mucho más elevado de sustancia seca en el capitulo.

El procentaje de la energia química de las hojas bajó rapidamente empezando del período de la formación del botón floral hasta la madurez fisiológica mientras que él del tallo empezó su decrecimiento en la fase del florecimiento. El porcentaje de la energia química del capítulo y semillas tuvo un crecimiento continuo hasta la madurez fisiológica.

La eficacia de la fotosíntesis por planta fue también significantemente mejor en el híbrido frente a las líneas parentales, en todos los estadios de desarrollo, sufiriendo la influencia del heterosis también desde este punto de vista. La eficacia de la fotosíntesis por partes individuales de planta tuvo una variación notable en función del estadio de crecimiento y desarrollo y del genotipo.