Research Article

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Forage yield, seed, and forage qualitative traits evaluation by determining the optimal forage harvesting stage in dual-purpose cultivation in safflower varieties (*Carthamus tinctorius* L.)

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Abstract: Safflower (*Carthamus tinctorius* L.), adapted to arid and semiarid regions, is grown for seed and petal production, but the present study aimed to evaluate the possibility of simultaneous forage and seed production in the autumn and middle types of safflower varieties in dual-purpose cultivation in semiarid areas in the shortfall forage period. An experiment was done based on a randomized complete block design with nine treatments and three replications at the Seed and Plant Improvement Institute, Agriculture Research, Education and Extension Organization, Karaj, Iran. The treatments included the cultivation of Parnian, Goldasht, and Golmehr varieties with the purpose of seed harvesting as control treatments; the same varieties (Parnian, Goldasht, and Golmehr), once with the aim of forage harvesting at 50% stem elongation stage and seed harvesting; and again with the aim of forage harvesting at 50% branching stage and seed harvesting. The results showed that forage harvesting at the 50% branching stage significantly increased the dry and fresh forage yield compared to the 50% stem elongation stage. The highest fresh and dry forage yields (DFY) (42,229 and 11,266 kg/ha) were related to the Golmehr variety at the 50% branching stage. Forage harvesting at the stem elongation stage decreased the crude protein, protein content, and digestibility compared to the branching stage in three safflower varieties. Parnian variety had the maximum seed yield (2,226 kg/ha) without forage harvesting. The highest seed yield in the second year (2018–2019) of the experiment belonged to the Golmehr variety (1,310 kg/ha) to harvest forage at 50% stem elongation (rapid stem growth) and seed harvest treatment, which compared to the first year (2017–2018), showed an increase of 25%. Finally, the forage harvested amount of all three varieties studied was higher in the branching stage than in the stem elongation stage. These results implied that the Golmehr variety (11,266 kg/ha DFY and 520 kg/ha seed yield) is for dual-purpose cultivation, and the Parnian variety (2,226 kg/ha seed yield) is suitable for only seed production for the semiarid region of Karaj in Iran and similar areas in terms of climate.

Keywords: branching stage, forage quantitative and qualitative yield, harvest stage, safflower, stem elongation stage

Abbreviations

ADF	acid detergent fiber
BHBH	bush height before forage harvest
BHPM	bush height at re-growth in the physiological maturity stage
CF	crude fiber
Cp	crude protein
DDM	digestible dry matter
DE	digestible energy
DFY	dry forage yield
DMI	dry matter intake
DP	digestible protein
FFY	fresh forage yield

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NDF neutral detergent fiber
NEL net energy of lactation
RFV relative feed value
TDN total digestible nutrients
WSC water-soluble carbohydrate

1 Introduction

Global requests for animal products will increase by 70% in 2050 compared to 2000, originating from universal population growth, increasing incomes, and urbanization. In the meantime, the increase in production, including the production of animal sources, strengthens the investigation of more efficient use of housing technologies and feed resources [1]. On the other hand, improving the sustainability of dairy products can be achieved by reducing the harm or negative impacts associated with dairy [2]. According to this opinion, producing sufficiently high-quality forage in the shortfall period during April in the semiarid regions of Karaj in Iran and similar areas in terms of climate as a negative effect on the production of dairy products is a way to overcome this challenge. Meanwhile, oilseed crops such as safflower have a remarkable role in fulfilling the energy requirements for humans and livestock [3]. Dual-purpose safflower genotypes were used to achieve research goals (autumn and mid-season safflower varieties). These genotypes can produce seeds and forage at the same time [4]. These varieties can be used as fresh forage (immediately harvested), silage forage (harvested at the end of the soft pulp stage), or seed harvesting [5].

Among edible oils for human beings, safflower seeds are one of the richest sources of unsaturated fatty acids like linoleic acid [3]. In addition to oil, this plant can also be used for animal feed [6]. It has been reported to be suitable for ruminant feed due to its high digestibility and significant dry matter forage yields of up to 22 t/ha [7]. It can be forage-grazed directly by livestock or preserved by ensiling or hay-making [8]. Compared to alfalfa-grass hay or a blend of vetch and oats, safflower forage has been effectively employed as the only feeding for various animals without negatively impacting dairy performance [9]. When picked between mid-budding and early flowering stages, safflower is an excellent feed because it is less thorny and, thus, more appealing to animals [10]. Safflower is often grown on low-fertility soils with few inputs and no irrigation [11].

Safflower has been cultivated successfully in dry and semiarid regions with finite water since it is a tap-rooted and drought-resistant plant [12]. Also, Aloe vera and Saffron (*Crocus sativus* L.) are no exception due to their tolerance potential as xerophytes [13,14]. It is one of the most adapted oilseed crops to dryland cropping systems [15]. Safflower has a higher feed value in dry conditions and stays green, making it an attractive forage in Mediterranean settings [9]. Therefore, it can be an essential forage for arid agro-climatic conditions due to its drought tolerance and good forage quality [16].

Nevertheless, it is sensitive to dry soil conditions in which kernel filling (flowering) is affected by water stress conditions [15]. To improve plant productivity, it is substantial to supply adequate water and nutrient acquisition in semiarid regions, typically characterized by variable and unpredictable rainfall, wide daily temperature ranges, frequent strong winds, and poor moisture-storing capacity of soils [17].

Forage analysis standard characteristics, such as neutral detergent fiber (NDF) and acid detergent fiber (ADF), are key forage quality evaluation attributes. The ADF content is a strong indicator of forage digestibility, while NDF is the indicator to determine intake potential [18–20]. The relative feed value (RFV) is an index that determines the consumption rate and the produced energy value and is used for comparing the forage quality in different varieties and treatments; the higher the RFV, the higher the forage quality [21].

The safflower green forage digestibility and intake have been evaluated mixed with vetch–oats in sheep as confined [22]. Safflower is an excellent source of nutrition for ruminants [16]. Forage crops are usually harvested to achieve the desired balance between yield and nutritional value. The forage quantity and quality are affected by several factors like varieties, harvesting time, harvesting, and storage methods, and the quality of forage in different parts of the plant is significantly different [19]. The harvest stage has a significant impact on safflower forage yield and quality [23,24].

Jabari et al. [25] examined the effects of harvesting time on the quantitative and qualitative of safflower. According to their results, the crude protein (Cp) content of safflower forage varied between 9 and 21% of dry matter, partly as a function of the growth days.

The forage digestibility decreases with further plant development and maturity because of the polymerization of water-soluble carbohydrates (WSCs) through cell wall lignification metabolism [26,27]. Previously, the early flowering stage has been reported as the appropriate harvesting time to achieve optimal safflower forage yield and quality [28]. However, there is a lack of information on the appropriate harvesting stage of safflower forage, the dual-purpose cultivation of safflower, and the simultaneous production of feed and seed.

Therefore, the present study aimed to evaluate seed yield potential and safflower varieties forage by determining the optimal forage harvesting stage in a dual-purpose cultivation system.

2 Materials and methods

This study was conducted as 2-year experiments at the Research Farm of Seed and Plant Improvement Institute, Karaj, Iran (35°47′19″N, 51°12′43″E, 1,322 m) during the cultivation seasons of 2017–2019. The studied area has a semi-arid climate with an average annual rainfall of 243 mm (based on 30 years of meteorological data from Alborz province) and average maximum and minimum daily temperatures of 30 and 1°C, respectively. Local climatic and edaphic data are presented in Figure 1 and Table 1, respectively. Rainfall and temperature information was received through Alborz province, Iran's automatic agriculture meteorological research station. This research used spineless varieties (Goldasht, Golmehr, and Parnian). The characteristics of the studied varieties are shown in Table 2.

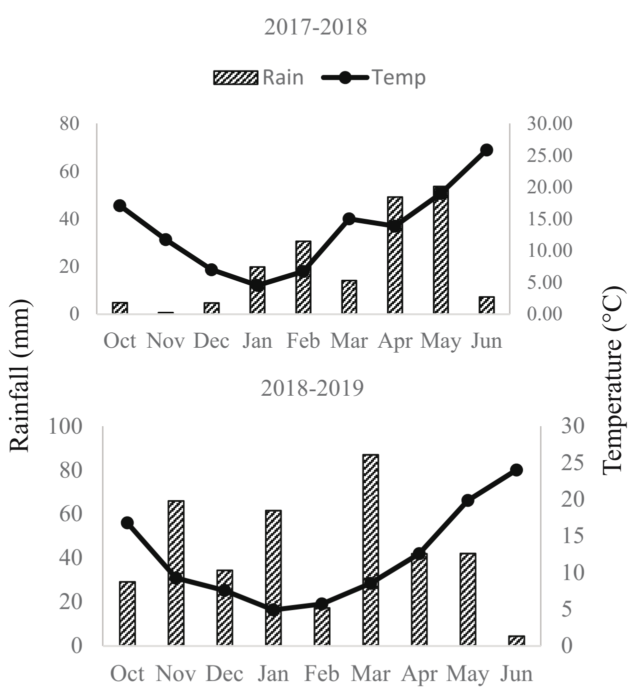

Figure 1: Rainfall and mean air temperature at the experimental site during 2017–2019.

The experiment was conducted over 2 years using a randomized complete block design with nine treatments and three replications, as described below.

Parnian, Goldasht, and Golmehr varieties were considered only with the aim of seed harvesting (as controls); the same varieties once for forage harvesting in 50% stem elongation stage, and then seed harvesting, and again for forage harvesting in the 50% branching stage, and then seed harvesting.

Before planting (October 12, 2017, and 2019), the field was disked and tilled to prepare a seedbed, and according to the soil test data (Table 1), the amount of fertilizer required for each experimental plot was calculated based on 100 kg/ha phosphate of ammonium and 50 kg/ha urea fertilizer mixed with soil, which was used simultaneously before being plowed once and harrowed twice. Potassium fertilizer was not used because the amount of absorbable potassium in the soil was higher than the critical level (Table 1). The plots consisted of four planting lines of 4 m. The sowing machine was used for planting on October 12, 2017, and in 2019. Planting was done in two rows on stacks with a width of 60 cm (row distance of 30 cm). The space between plants on rows was 4 cm, 30 kg of seed was utilized per hectare, and the ultimate plant density was 83 p/m2.

During the rosette stage (six leaves), Haloxyfop-R-Methyl EC 10.8% w/v (Gallant supper) herbicide was used at a ratio of 1:1,000 to fight narrow-leaved weeds. Safflower fly was a problem, even though the available varieties did not suffer from any particular disease.

During the growth period, Diazinon 60% EC (Basudin) was used to the extent of 1 l/ha to control the safflower fly (*Acanthiophilus helianthi* L.).

Collecting forage samples in spring (in April and May), depending on the type of treatment in the 50% stem

Table 1: Soil physicochemical properties for a field experiment carried out in Karaj, Iran

Cropping year	Soil depth (cm)	Sand (%)	Clay (%)	Silt (%)	Soil texture	pH	EC (ds/m)	OC (%)	N (%)	P (ppm)	K (ppm)
2017–2018	0–30	18	30	52	Silty clay loam	7.24	2.22	0.51	0.12	8.4	570
2018–2019	0–30	20	32	48	Silty clay loam	7.8	1.0	0.58	0.14	8.2	460

Abbreviations: pH: potential of hydrogen; EC: electrical conductivity; OC: organic carbon; N: nitrogen; P: phosphorus; K: potassium; ppm: parts per million.

Table 2: Some agronomic characteristics and phenological of the three safflower varieties under study [44,69]

Agronomic characteristics	Variety		
	Goldasht	Golmehr	Parnian
Growth habit	Spring (Cold-tolerant)	Autumn	Intermediate
Flower color	Red	Red	White
Thorn condition	Without thorns	Without thorns	Without thorns
Height (cm)	130–150	150–180	140–160
Stem diameter (mm)	9.42	16.62	8.17
Head diameter (mm)	35.8	27.9	29
Number of sub-branches	8	8	8
Average grain yield (kg/ha)	1,700–2,000	2,700–2,900	2,800–3,000
Thousand grain weight (g)	35–40	25–30	39–40
Seed oil content (%)	24–25	25–27	24–25
Seed shattering resistance	Resistant	Resistant	Resistant
Reaction to cold	Tolerant	Tolerant	Tolerant
Days until flowering (days)	213	221	213
Growing degree days until flowering	1,282	1,383	1,282
Physiological maturity	Early maturity	Late maturity	Early maturity

Abbreviations: cm: centimeter; mm: millimeter; kg/ha: kilogram per hectare; g: gram.

elongation or 50% branching stages, to measure the fresh and dry forage yield (DFY) was done by removing the marginal effects (first and last rows, half a meter above and below each experimental plot). For this purpose, cutting was done from a height of 20 cm above the crown using scissors from the two middle rows (four planting lines) with a length of 3 m. The volume of the collected sample was 3.6 m^{-2} from each experimental plot. The time of 50% elongation of the stem is determined by observing the first internode with a length of 1 cm in 50% of the plants in each plot. "After the stem elongation stage is the "branching" stage where branching occurs, so the time of 50% branching was determined by observing branching at an angle of 30–70° in 50% of the plants in each plot" [29].

Immediately, fresh forage yield (FFY) weight was determined with an accurate scale, and after being oven-dried at 70°C until constant weight, the dry matter yield of the forage was determined.

To measure bush height, the number of ten plants in each plot was randomly selected, and the bush height from the crown to the end of the inflorescence was measured using a ruler in centimeters in two stages: first, before the collection of forage samples and again after re-growth, were carried out at the physiological maturity stage. "Physiological maturity time is when the heads turn yellow, and only traces of green can be seen on the bracts" [29].

After collecting samples in forage harvest treatments, urea fertilizer (at 70 kg/ha) was used once to improve seed production. Also, irrigation was done three times with a furrow irrigation system (each time with a volume of 670 m^{-3} with a time interval of 7 days). Bush height was assessed twice: first before forage harvest at branching (bush height before forage harvest [BHBH]) and second following re-growth in physiological maturity (bush height at re-growth in the physiological maturity stage [BHPM]).

The harvesting of safflower varieties to determine the seed yield at the harvested maturity stage in July (July 16, 2017, and 2019) was carried out by hand on an area equal to 3.6 m^{-2}. Also, the threshing operation and the determination of seed yield were carried out by hand. In the harvested maturity, 75% of the heads are entirely brown, and the grains are easily separated from them [29].

The percentage of forage ash was determined using an electric furnace and the following formula [30] (equation (1)):

$$\%\text{Ash} = \frac{W_3 - W_1}{W_2 - W_1} \times 100, \quad (1)$$

where W_1 is the plant weight, W_2 is the plant weight and dry matter plant, and W_3 is the plant weight and ash (in g).

Digestible dry matter (DDM) was assessed by a two-step digestion method [31]. The dry tissue Cp content was determined using the Kjeldahl method. Its ADF, NDF, WSC, and crude fiber (CF) contents were determined according to Soest [32], and the ash content was measured by burning the samples at 500°C for 5 h [32]. RFV (%), dry matter intake (DMI, % of body weight), total digestible nutrients (TDN, % of DM), and net energy of lactation (NEL, Mcal/kg DM) were calculated using the following equations (equations (2)–(6)) [33,34]:

$$RFV = DDM \times DMI \times 0.775, \quad (2)$$

$$DDM = 88.9 - (0.779 \times ADF) \quad (3)$$

$$DMI = 120/NDF, \quad (4)$$

$$TDN = (-1.291 \times ADF) + 101.35, \quad (5)$$

$$NEL = (1.044 - (0.0119 \times ADF)) \times 2.205. \quad (6)$$

Digestible protein (DP, % of DM) and digestible energy (DE, Mcal/kg DM) were calculated using the following equations (equations (7) and (8)) [35]:

$$DP = (\text{Crude protein} \times 0.9) - 3, \quad (7)$$

$$DE = TDN \times 0.04409. \quad (8)$$

2.1 Statistical method

After the Bartlett test was carried out to check the uniformity of data variance and test assumptions for the variance analysis, a composite analysis of variance was carried out, including the normalization of the data, the normal distribution of the test's remaining errors, and the error uniformity test (p = 0.05) [36]. Analyses of variance were performed using the Statistical Analysis System software v9.1 package (SAS Institute, Cary, NC, USA) with six treatments for forage quality traits and nine treatments for grain yield. The treatment mean values were compared using Duncan's multiple range test tests at a 0.05 probability level.

3 Results and discussion

3.1 Bush height

The ANOVA results showed that, except for the interaction effect of cultivar*year, the year (p value = 0.05) and the variety (p value = 0.01) significantly affected BHBH (Table 3). BHBH in the second cropping year (124.8 cm) increased by 4.25% compared to the first year (119.5 cm; Table 4). Low temperatures, particularly in April, May, and June, along with increased rainfall in the second year, have proved beneficial in raising the bush height (Figure 1). These results are in agreement with those of Sefaoglu and Ozer [37].

The Goldasht variety, collected during the stem-elongation stage, had the shortest bush height (102.50 cm), and the Golmehr and Parnian varieties (harvested during the branching stage) had the greatest BHBH (p = 0.05) (Figure 2). The superior height of the Golmehr variety compared to other varieties is due to its genetic potential. The results are in agreement with those of Bahadorkhah and Kazameini [38].

Table 3: ANOVA for some quantitative traits of three safflower varieties (Goldasht, Golmehr, Parnian)

Source of variation	df	Mean squares			
		BHBH	BHPM	FFY	DFY
Year	1	256.0*	144.0**	619,113,924^{ns}	27,027,868*
Rep (year)	4	27.1	5.5	200,285,383	2,999,357
Variety	5	1259.5**	578.5**	108,556,530**	5,019,352**
Variety * year	5	7.6^{ns}	4.8^{ns}	3,813,966^{ns}	592,818^{ns}
Error	20	22.6	13.0	3,721,799	772,523
C.V. (%)	—	3.8	8.1	5.4	8.6

Source of variance	df	CP	WSC	ADF	Mean squares				
					NDF	CF	Ash	DP	SD
Year	1	0.2^{ns}	1.4^{ns}	6.3^{ns}	7.6^{ns}	10.3^{ns}	0.17*	0.18^{ns}	1775,978**
Rep (year)	4	7.9	6.14	3.6	2.0	24.8	0.2	6.39	39,421
Variety	5	28.6*	53.19**	59.9**	33.7^{ns}	219.8*	0.78**	23.20*	3721,193**
Variety * year	5	0.1^{ns}	0.1^{ns}	0.9^{ns}	3.2^{ns}	1.1^{ns}	0.2^{ns}	0.1^{ns}	449,848**
Error	20	10.3	4.1	10.3	13.1	41.1	0.18	8.3	27,494
C.V. (%)	—	18.3	16.8	9.6	11.4	10.7	4.2	22.7	5.16

*, **, and ^{ns} mean significant at 5 and 1% probability level and non-significant, respectively.
Abbreviations: df: degrees of freedom; Rep: replication; C.V.: coefficient of variation; BHBH: bush height before forage harvest; BHPM: bush height at re-growth in the physiological maturity stage; FFY: fresh forage yield; DFY: dry forage yield.
Abbreviations: Cp: Crude protein; WSC: water-soluble carbohydrate; ADF: acid detergent fiber; NDF: neutral detergent fiber; CF: crude fiber; DP: digestible protein; SD: seed yield.

Table 4: ANOVA of the effect of harvesting time of safflower varieties on the trait of seed yield

Source of variation	df	Mean squares Seed yield
Year	1	1,775,978**
Replication (year)	4	39,421
Treatments	8	3,721,193**
Year * treatments	8	449,848**
Error	32	27,494
C.V. (%)	—	5.16

*, **, mean significant at 5 and 1% probability level, and non-significant, respectively.
Abbreviations: df: degrees of freedom; Rep: replication; C.V.: coefficient of variation.

Table 5: Effect of cropping year on BHBH, bush height at plant re-growth, seed yield, and plant ash content

Cropping year	BHBH	BHPM	ASH
	(cm)		(%)
1st year	119.5[b]	42.3[b]	10.2[a]
2nd year	124.8[a]	46.3[a]	10[b]

Data are the mean of three varieties.
Within each column, mean values having similar letters have no significant difference at a 5% probability level (Duncan´s test).
Abbreviations: BHBH: bush height before forage harvest at branching; BHPM: Bush height at re-growth in the physiological maturity stage; ASH: plant ash content; cm: centimeter.

Year and variety significantly affected BHPM (Table 3). When the bush height is compared over the years analyzed, there is an increase in this attribute in the second year following re-growth (Table 5). The occurrence of more rainfall in the second year was effective in increasing the height of the plant (Figure 2).

The Golmehr variety harvested at the stem elongation stage had the highest BHPM (59.6 cm), which indicates a 15.2% increase compared to the Golmehr variety harvested at the branching stage (50.6 cm) (Figure 2). Mousavi-Ojagh [39] reported that various safflower varieties have different bush heights. He stated that Iranian native and commercial varieties (Soffeh, Parnian, and Golmehr) had the highest bush height. This is consistent with our results. Furthermore, Rahmani [40] reported a significant difference among Iranian safflower varieties from the point of view of bush height. The results of this study indicated that Golmehr and Goldasht had the lowest plant height, with 142.41 and 111.57 cm, respectively.

3.2 Forage and seed yield

The results of ANOVA showed that the varieties significantly affected FFY ($p = 0.01$), while year and variety × year interaction had no significant effect on this trait (Table 3). DFY was affected by year ($p = 0.05$) and variety ($p = 0.01$). Variety × year interaction effect on dry forage production was meaningless (Table 3). Safflower dry matter yield ranges from 3.5 to 8 t/ha [41,42].

Golmehr variety at the branching stage had the highest FFY by 42,229 kg/ha, which had a statistically significant difference from other varieties (Figure 3). The highest DFY was related to the Golmehr variety at the 50% branching

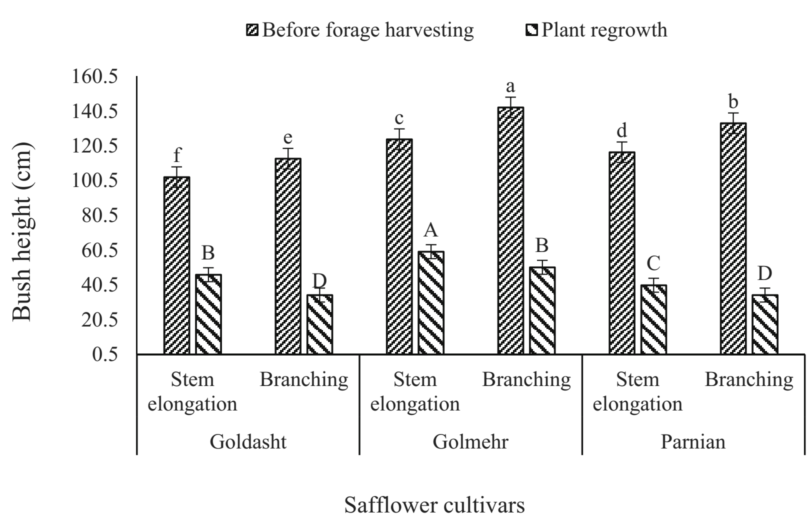

Figure 2: BHBH (stem elongation, branching) and at plant re-growth at maturity for three safflower varieties (Goldasht, Golmehr, Parnian). Mean values having similar letters have no significant difference at a 5% probability level (Duncan's test). Data are the mean of 2 years.

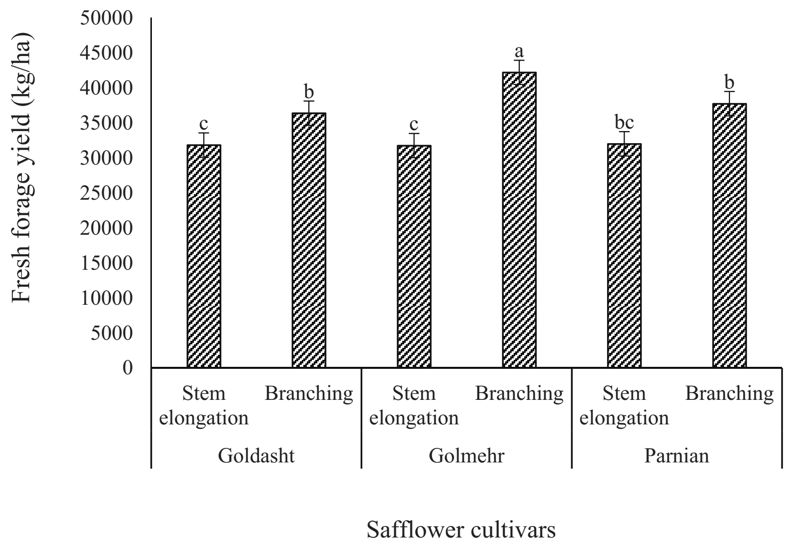

Figure 3: FFY for three safflower varieties (Goldasht, Golmehr, Parnian). Mean values having similar letters have no significant difference at a 5% probability level (Duncan's test). Data are the mean of 2 years.

stage at the rate of 11,266 kg/ha, which had a statistically significant difference from the other varieties (Figure 4).

Harvesting forage at the 50% branching stage caused a significant increase in the FFY of the studied varieties compared to the 50% stem elongation stage (Figure 3). The same was true for DFY (Figure 4). Varieties at the 50% stem elongation stage did not differ significantly in FFY and DFY (Figure 3).

Cazzato et al. [43] examined the effect of harvest date at three different stages of safflower (the appearance of primary buds, the appearance of secondary and tertiary buds, and 25% of the flowering stage) in southern Italy. They reported that the DFY of safflower ranged from 4.5 t/ha (primary buds) to 11.6 t/ha (25% of the flowering stage).

The results of ANOVA showed that the effects of year, variety, and year × variety interaction on the safflower seed yield were significant (Table 3). The highest seed yield in both years of the experiment (2,226 and 2,215 kg/ha, respectively) in treatments without forage harvesting was obtained in the Parnian variety (Figures 5 and 6). The

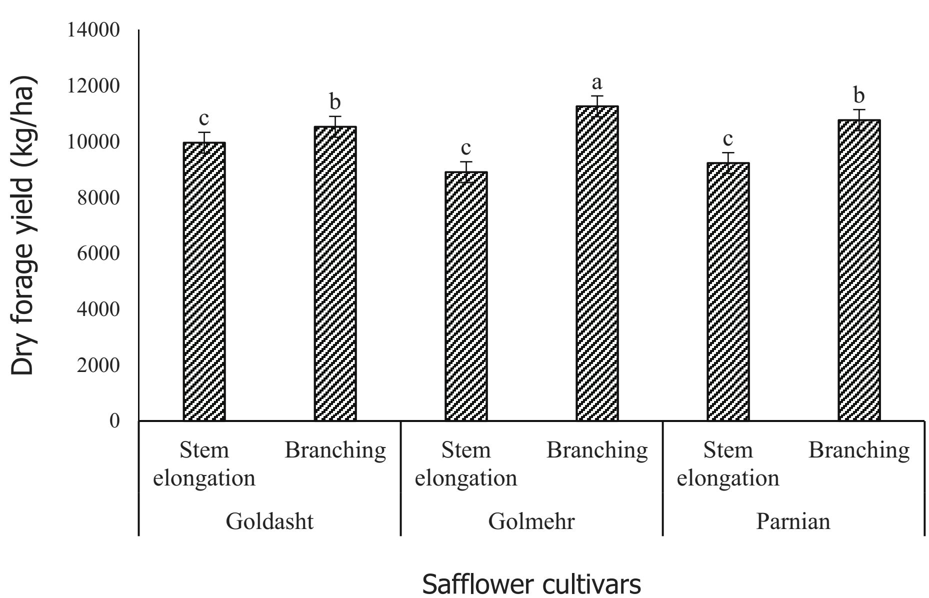

Figure 4: DFY for three safflower varieties (Goldasht, Golmehr, Parnian). Mean values having similar letters have no significant difference at a 5% probability level (Duncan´s test). Data are the mean of 2 years.

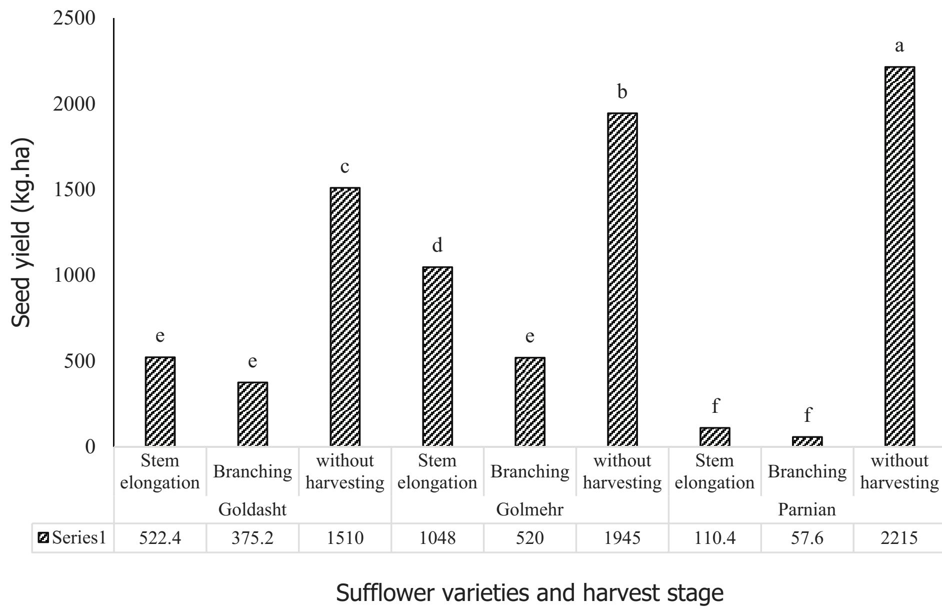

Figure 5: The mean comparison interaction effects of the year and variety on seed yield of three safflower varieties (Goldasht, Golmehr, Parnian) during the first year. Mean values having similar letters have no significant difference at a 5% probability level (Duncan's test).

mentioned variety had a higher yield than the Golmehr and Goldasht varieties in both years of the experiment (Figures 5 and 6).

It seems that the reason for the superiority of the Parnian variety is the genetic potential of this variety, which has produced the highest seed yield compared to other studied varieties (Table 2). Similar results were obtained by Jabari et al. [44].

The highest seed yield in the second year (2018–2019) of the experiment belonged to the Golmehr variety (1,310 kg/ha) with the purpose of harvesting forage at 50% stem elongation (rapid stem growth) and seed harvest, which compared to the first year (2017–2018), showed an increase of 25% (Figures 5 and 6). The occurrence of more rainfall in the second year was effective in increasing the seed yield (Figure 1).

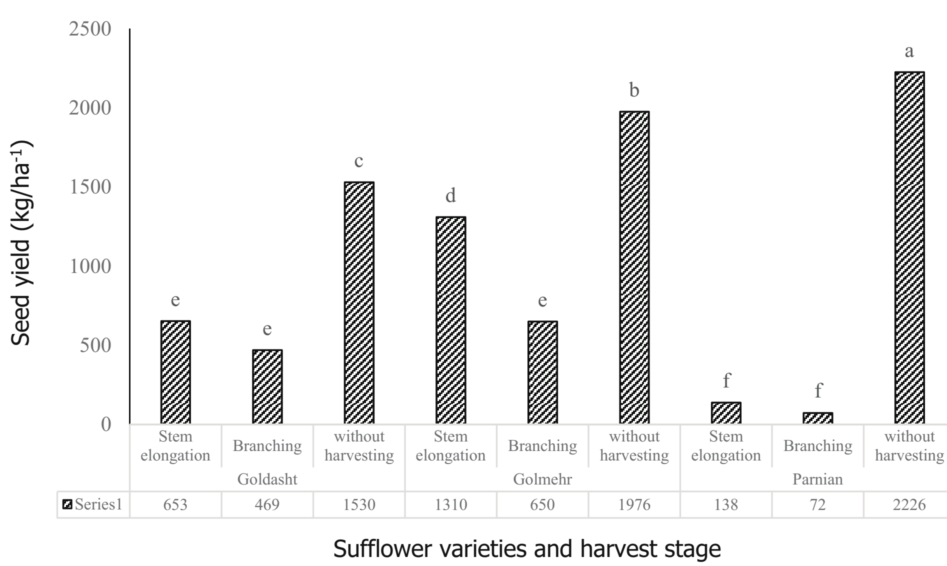

Figure 6: The mean comparison interaction effects of the year and variety on seed yield of three safflower varieties (Goldasht, Golmehr, Parnian) during the second year. Mean values having similar letters have no significant difference at a 5% probability level (Duncan's test).

Due to late maturity, the Golmehr variety had more time to reach physiological maturity and produced the highest seed yield than other studied varieties (Table 2). The lateness of the Golmehr variety compared to others is related to its genetic potential (Table 2). Late maturity has led to an increase in the use of environmental factors (light, temperature, humidity, and nutrients), and the plant has produced more plant materials with more photosynthesis, which has led to improved yield [45].

In this connection, it is stated that the seed yield of safflower in rain-fed conditions is 1,500 kg/ha [46]. Also, the role of the number and intensity of rainfall in the yield of agricultural products has been mentioned [47].

According to the results, compared to dual-purpose cultivation, the seed yield in the treatments without forage harvesting was significantly higher in the studied varieties. The reason is that the growth tips are left intact, and no biomass is removed. A decrease in seed yield after forage harvesting has also been reported by Neely et al. [48].

For all varieties, the seed yield obtained from forage harvesting in the branching stage was less than that in the stem elongation stage (Figures 5 and 6). In agreement with these results, Begna et al. [49] reported that forage harvesting reduced seed yield even before bolting. Low seed yield in the treatment of forage harvesting at the branching stage could be due to the plant's less opportunity for re-growth and closer to the reproductive stage (flowering) to compensate for forage harvest damage.

The lower yields of the re-growth at harvesting in the 50% branching stage are probably associated with the consumption of WSCs for supplying energy for plant maintenance (Table 6). A similar yield reduction during re-growth was also observed in other sorghum varieties [50].

Table 6: Forage quality indices for three safflower varieties (Goldasht, Golmehr, and Parnian)

Treatments	CP	WSC	CF	Ash
	(%)			
Goldasht; stem elongation	16.4^{b}	15.7^{a}	29.8^{b}	10.2^{ab}
Goldasht; branching	19.2^{a}	13.2^{bc}	35.5^{a}	10.6^{a}
Golmehr; stem elongation	16.6^{b}	8.5^{d}	32.0^{ab}	9.5^{c}
Golmehr; branching	19.8^{a}	8.4^{d}	31.5^{ab}	10.3^{ab}
Parnian; stem elongation	13.9^{c}	14.0^{ab}	28.6^{b}	10.0^{bc}
Parnian; branching	18.5^{ab}	11.8^{c}	32.0^{ab}	10.1^{ab}

Data are the mean of two experimental years.
Within each column, mean values having similar letters have no significant difference at 5% probability level (Duncan´s test).
Abbreviations: CP: crude protein; WSC: water-soluble carbohydrate; CF: crude fiber.

3.3 Forage quality

The results of ANOVA showed that the effect of the year was significant only on the amount of plant ash content (p = 0.05) and had no significant impact on the other studied quality parameters (Table 3). The mean comparison results of the effect of cropping year on plant ash content showed that the ash content in the second year significantly decreased compared to the first year (10.2 compared to 10%) (Table 5).

According to the results presented in Table 3, the safflower varieties harvested at different stages significantly affected forage quality indices, except for NDF. The forage quality assessment in different harvesting stages showed that Cp forage in the branching stage was higher than in the stem elongation stage (Table 6).

The highest protein content obtained in the Golmehr variety was harvested at the branching stage by 19.8%, which had no significant difference from Goldasht treatments (19.2%) and Parnian harvested at the branching stage (18.5%) (Table 6). Plant harvesting at the stem elongation stage diminished the protein content in studied safflower varieties (Table 6). When the leaf-to-stem ratio has decreased, Cp production has also fallen [51].

Furthermore, data revealed that delaying plant harvesting produced a considerable drop in safflower plant WSC concentration, with Goldasht and Parnian varieties (early maturity varieties) having the highest WSC content by 15.7 and 14%, respectively, while Golmehr varieties (late maturity variety) had the lowest WSC content at both harvesting stages (8.4% at branching and 8.5% at stem elongation stage; Table 6). The reason for this reduction is that the later the harvesting time is, the lower the quality of the forage yield increases.

Cazzato et al. [28] reported that WSC in safflower forage ranged from 128 (primary buds) to 105 and 100 g/kg dry matter at secondary and tertiary bud flowering stages, respectively. Damame et al. [52] examined different harvest times on the quality of millet. They claimed that the highest Cp production was acquired during the milking stage and that the delay in harvest time resulted in a fall in Cp.

In the opinion of Hilscher et al. [53], the WSC percentage increases with plant age. Raei et al. [54] stated that unfavorable climatic conditions, such as high temperatures and low rainfall during the growing season, reduced forage quality by decreasing the production of soluble carbohydrates.

CF was significantly affected by experimental treatments (varieties) (Table 3). The Goldasht variety harvested at the branching stage had the highest CF content of 35.5%, which had no significant difference with other treatments, excluding the Goldasht and Parnian varieties harvested at stem elongation (29.8 and 28.6%) (Table 6). Hence, as plant growth has grown, so has the quantity of plant fiber. This is because as the plant grows, the number of supporting and reinforcing tissues, such as sclerenchyma tissue, increases; hence, with the conclusion of the plant development phase and an increase in the proportion of structural carbohydrates, the percentage of plant fiber increases [55].

Also, Table 6 shows that the Golmehr variety harvested at the stem elongation stage has the lowest ash content compared to the other varieties and the same variety at the branching stage by 9.5 and 10%, respectively. At the branching stage of 50%, the Golmehr variety had a higher leaf area index and a higher leaf-to-stem ratio than other varieties (results not shown). More leaf surfaces with increasing photosynthesis had caused more carbon absorption per unit area and increased ash content [56].

3.4 Forage digestibility

The results of ANOVA showed that the studied varieties significantly affected DDM (Table 7). Forage harvesting had the maximum dry matter digestibility in the branching stage in the Goldasht and Parnian varieties, with an average of 71.5 and 68.2%, respectively, and in the stem elongation stage in the Goldasht variety (66.9%) (Table 8). Among the studied varieties, the Goldasht variety at the branching stage had the highest digestibility indices value compared to other varieties harvested (Table 8).

Forage harvest at the stem elongation stage decreased the digestibility of dry matter in all safflower varieties (Table 8). The lowest level of this characteristic was seen in the forage harvest treatment at the stem elongation stage in the Golmehr variety, with an average of 61.8% (Table 8). According to the results presented in Table 8, harvesting at the branching stage resulted in higher forage digestibility compared to the stem elongation stage.

In other words, the growth stage and getting close to maturity affected forage digestibility. The results are in agreement with the results of Atis et al. [57]. Landau et al. [58] found that the leaves of safflower forage were more digestible *in vitro* than the stems. Generally, high-quality forage has a high yield and the highest digestibility, but not always. Also, stems are more concentrated by cell walls than leaves; thus, stems are often less digestible. With increasing plant growth and the number of leaves in the branching stage, dry matter digestibility is enhanced.

The highest DMI by livestock was observed in forage harvesting treatment in the branching stage in the Goldasht variety with an average of 2.48%, which was not significantly different from the forage harvesting treatment in

Table 8: Forage digestibility indices for three safflower varieties (Goldasht, Golmehr, Parnian)

Treatments	DDM	DMI	TDN	RFV
	(%)			
Goldasht; stem elongation	66.9^{ab}	2.17^{ab}	59.8^{ab}	107.6^{b}
Goldasht; branching	71.5^{a}	2.48^{a}	64.2^{a}	129.0^{a}
Golmehr; Stem elongation	61.8^{c}	1.85^{bc}	52.5^{c}	85.5^{c}
Golmehr; branching	65.9^{bc}	1.80^{c}	56.0^{bc}	86.1^{c}
Parnian; stem elongation	63.9^{bc}	1.94^{bc}	56.6^{bc}	93.4^{bc}
Parnian; branching	68.2^{ab}	2.02^{bc}	60.4^{ab}	100.7^{bc}

Data are the mean of two experimental years.
Within each column, mean values having similar letters have no significant difference at the 5% probability level (Duncan´s test).
Abbreviations: DDM: digestibility dry matter; DMI: dry matter intake; TDN: total digestible nutrients; RFV: relative feed value.

Table 7: ANOVA for forage digestibility indices for three safflower varieties (Goldasht, Golmehr, Parnian)

Source of variation	df	Mean squares						
		DDM	DMI	TDN	RFV	NE_L	DE	DP
Year	1	3.10^{ns}	0.011^{ns}	10.6^{ns}	77.1^{ns}	0.04^{ns}	0.020^{ns}	0.18^{ns}
Rep (year)	4	6.3	0.042	6.0	181.1	0.002	0.011	6.39
Variety	5	3.68**	0.373**	99.9**	1614.7**	0.041**	0.194**	23.20*
Variety * year	5	1^{ns}	0.001	0.1	0.7	0.001	0.001	0.01
Error	20	8.14	0.071	17.2	280.7	0.007	0.033	8.3
C.V. (%)	—	5.8	13.0	7.1	16.6	5.9	7.1	22.7

Data are the mean of two experimental years.
*, **, and ^{ns} mean significant at 5 and 1% probability level and non-significant, respectively.
Abbreviations: DDM: digestibility dry matter; DMI: dry matter intake; TDN: total digestible nutrients; RFV: relative feed value; NEL: net energy for lactation; DE: digestible energy; DP: digestible protein; df: degrees of freedom; Rep: replication; C.V.: coefficient of variation.

the stem elongation stage in the Goldasht variety (2.17%) (Table 8).

Similar results have been obtained by Davis [59]. During his research, he stated that the estimated apparent DMI did not differ when comparing steers consuming Alamo hays harvested at the boot and early flowering stage. As the age of the plant increases, the amount of non-structural carbohydrates decreases, and the amount of fiber, lignin, and structural carbohydrates is enhanced [60]. High amounts of structural carbohydrates such as lignin decrease the forage quality by reducing the amount of DMI and diminishing its digestibility [57].

The forage harvesting treatment at the branching stage in the Goldasht variety, with an average of 64.2%, produced the highest amounts of TDN, which was not significantly different from the forage harvesting treatments in the branching stage in the Parnian variety (60.4%) and stem elongation stage in the Goldasht variety (59.8%) (Table 8).

The TDN forage parameter, which is related to the NDF and ADF concentration of the forage, indicates nutrients in the forage that are available to livestock [61]. Increasing the absorption of nutrients, especially nitrogen, increases digestible nutrients in forage, and genotypes with higher nutrient absorption capacity have higher TDN [62].

Late forage harvest generally enhanced the RFV of safflower varieties. The maximum RFV was noted in the forage harvesting at the branching stage in the Goldasht variety with an average of 129%, which indicated superiority over other treatments (Table 8).

The safflower forage had more RFV at the branching stage compared to the stem elongation stage (Table 8); however, the Goldasht variety showed a greater RFV at the stem elongation stage than the other varieties did at the branching stage (Table 8). Based on the results of ANOVA, NEL, DE, and DP were significantly affected by the harvesting stage of different safflower varieties (Table 7).

According to Figure 6, late harvest of forage had no significant effect on the NEL of safflower varieties. The highest NEL was obtained in the forage harvesting treatment in the branching stage in Goldasht and Parnian varieties with an average of 1.54 and 1.47 Mcal/kg dry matter, respectively, which had no statistically significant difference with the forage harvesting in the stem elongation stage in the Goldasht variety.

The lowest amount of NEL was observed in the forage harvesting treatment at the stem elongation stage in Golmehr and Parnian varieties with an average of 1.31 and 1.39 Mcal/kg dry matter, respectively, which had no significant difference with the forage harvesting in the branching stage of Golmehr variety (1.38 Mcal/kg dry matter; Figure 6).

The highest DE value was observed in the forage harvesting treatment at the branching stage in the Goldasht and Parnian varieties by 2.83 and 2.66 Mcal/kg dry matter, respectively, which had no significant difference with the forage harvesting in the stem elongation in the Goldasht variety (2.63 Mcal/kg dry matter; Figure 6).

Figure 7 shows the mean comparison of safflower varieties on plant forage DP content. As can be observed in Figure 7, harvesting at the branching stage resulted in the highest DP content, and CP increased compared to the harvest at the stem elongation stage. Forage harvest at an early stage of maturity is expected to result in forage with a high

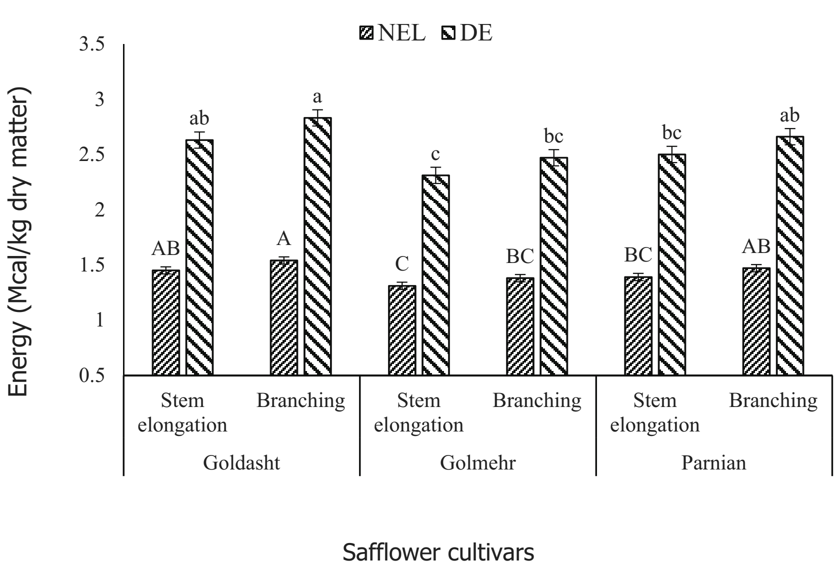

Figure 7: Plant forage, net lactation energy, and DE for three safflower varieties (Goldasht, Golmehr, Parnian). Mean values having similar letters have no significant difference at a 5% probability level (Duncan's test). Data are the mean during 2 years of study.

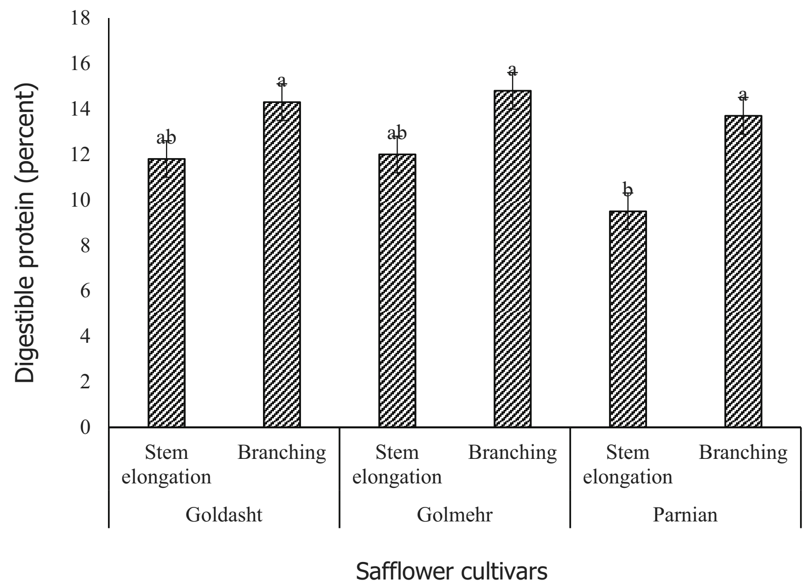

Figure 8: Plant forage, DP content for three safflower varieties (Goldasht, Golmehr, Parnian). Mean values having similar letters have no significant difference at a 5% probability level (Duncan's test). Data are the mean during 2 years of study.

concentration of energy and, therefore, may be a prerequisite for increased energy intake and production [63].

In general, later forage harvest increased the DP, with the highest DP observed in the forage harvesting treatment in the branching stage in the Golmehr variety (average of 14.8%), which had no significant difference with other treatments, except the Parnian variety harvested at stem elongation stage (by 9.5%; Figure 7).

Feed intake depends on the physical characteristics and ration chemical composition [64] and is influenced by digestibility and rate of passage from the rumen [65]. Alstrup et al. [66] found that the digestibility of rations positively correlated with fecal dry matter concentration.

Also, Demirbag et al. [67] stated that the phenological growth stage on forage quality had a significant effect. The close matching of nutrient requirements and feed quality is needed for efficient animal production. They found that the higher forage quality was recorded at the first growth stage. Stems containing superior amounts of WSCs, such as sweet sorghum, may have a higher digestibility rate than leaves containing lower WSCs [68]. An increase in the proportion of panicles with advancement in maturity was reported for forage sorghum (Figure 8) [57].

4 Conclusions

The typical Mediterranean climate generates a high demand for evaporation in late spring (ca. April–June) when rainfall is low, considerably enhancing severe water deficit risks. Forage shortage in late spring in semiarid areas such as Karaj and other similar areas is a problem that livestock farmers and the dairy industry face. On the other hand, countries like Iran and other parts of the world have limited edible oil production. To overcome these problems, dual-purpose safflower genotypes (Golmehr autumn and Parnian middle-type varieties) were investigated. Finally, the forage harvested amount of all three varieties studied was higher in the branching stage than in the stem elongation stage. The Golmehr autumn variety (11,266 kg/ha DFY and 520 kg/ha seed yield) is for dual-purpose cultivation, and the Parnian middle-type variety with high seed yield (2,226 kg/ha seed yield) is suggested for seed production in semiarid regions. Our suggestions for future studies are to increase the number of studied cultivars in the dual-purpose cultivation of safflower along with the application of drought stress treatments due to the high resistance of safflower to drought. Also, providing more portions of nitrogen fertilizer after forage harvesting can accelerate vegetative growth and increase seed yield.

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