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Significance of Sowing Date, Variety and Potassium Fertilization for Frost Control in Faba Bean

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Abstract: **Though faba bean (Vicia faba L.) is a leading pulse crop grown in the central highlands of Ethiopia, frost is a threat of its production for decades. Therefore, a field experiment was conducted during 2017and 2018 to evaluate the effect of sowing date, variety and potassium against frost in faba bean at Debre Brehan Agricultural Research Center main station (Faji). Factorial combinations of two sowing dates, two varieties of faba bean ('Wolki'- large seeded and 'Dagm'-small seeded) and four levels of potash (K_2O) (0, 50, 100 and 150 kg/ha) were tested in RCBD. Potassium chloride was used as a source of K_2O fertilizer. Sowing date and variety showed significant ($p<0.05$) effects on most of the studied parameters in both years and combined over years while K_2O showed significant ($p<0.05$) effects only on number of seeds per pod, hundred seeds weight and germination efficiency in 2017. Interactions with K_2O showed significant ($p<0.05$) effects only on some parameters considered. According to ANOVA and economic analysis results K_2O at the rate of 50 kg/ha found economically optimum for variety 'Wolki' at first/early sowing as highest grain yield and lowest frost injury was obtained at this level. Hence, time of split application of this level should be further studied. On the other hand, application of K_2O showed no significant contribution for the small seeded variety 'Dagm' during early sowing. However, in the case of early frost occurrence (though time of frost occurrence could not be predicted); use of K_2O might be considered as an option.**

Keywords: **Active methods, Dagm, Option, Parameters, Passive methods, Vicia faba L., Wolki.**

1. INTRODUCTION

Low temperature (chilling and freezing/frost) injury can occur in all plants, but the mechanisms and types of damage vary considerably (Snyder *et al*., 2005) though it is always been a threat of crop production in the highlands of North Shewa, Ethiopia. The above authors also noted that it is not cold temperature but ice formation in the cell that actually injures the plants. According to Anonymous (2019), low temperature injury is classified into three groups: 1, chilling injury is damage to plant parts caused by temperatures above the freezing point (0°C). 2, Frost injury and freeze injury which are closely related, and the damage looks the same. In both cases, ice crystals form in water-filled plant tissues, dehydrating cells and disrupting membranes. The result is collapsed and/or darkened plant parts. The difference is frost damage occurs during a radiation freeze (produced locally and occurs on clear, calm nights when plants radiate or lose more heat into the atmosphere than they receive) whereas freeze damage occurs during an advection freeze (occurs when an air mass with a temperature below freezing moves from another region into an area and displaces warmer air, causing the temperatures of plants to become low enough for ice crystals to form within their tissues).

Plants protect themselves against winterkill by a process called acclimatisation by storing osmotically effective substances such as sugar and potassium within their cells which serve as antifreeze agents, by lowering the cell sap's freezing point, thereby maintaining cell functionality (K+S KALI GmbH, 2015). Because potassium is very soluble ion, high potassium levels increase solute concentration and lower the freezing point of water in plant tissue (Waraich *et al*., 2012). It is present in the plants in concentrations ranging from 50–150 mM in the liquid parts; the cytoplasm and the vacuole (Leigh and Jones, 1984; cited by Kant and Kafkafi, n.d.). It is reported that passive methods - such as site selection, land clearing, crop management, and soil management activities and active methods **-** such as covering, fog or smoke, sprinkling, heating are used to protect frost injury. Passive methods are used well in advance of the actual freeze dangers (which are probably the most economical and effective) while active methods are not necessary in most seasons because they are expensive and can only be afforded when the crop has a high value per unit area (Snyder *et al*., 2005).

According to Hawthorne (2007) strategies to minimize frost damage in pulses work in combinations of: selecting a more tolerant species; selection of variety that avoids peak flowering and early podding during the period of most risk or has extended flowering to compensate for losses to frost; or ensuring that most grain is sufficiently filled to avoid damage when frost occurs. Targeting flowering and early podding to periods of least frost risk is achieved through combinations of sowing date and variety choice for flowering time and flowering duration. Among four pulse crops, faba bean (*Vicia faba* L.) is said to be the most frost tolerant followed by field pea, lentil, and chickpea (Phelps, 2016) due to thick pods which assist in protecting the seed during filling (Hawthorne, 2007). However, in high altitude areas of North Shewa, faba bean production is highly limited and/or hindered by frost problem. To overcome this problem, more than 1000 faba bean genotypes had been tested though none of the genotypes found tolerant. On the other hand, some faba bean varieties (both major and minor types) resistant to frost have been reported somewhere else (Link, *et al*., 2008). In field pea it is reported that tall cultivars are more susceptible to frost injury than shorter ones and colored seeded cultivars are resistant to cold injury. An observation trial conducted in previous years at the then Sheno agricultural research center in Ethiopia indicated that the effects of potassium fertilizer, mulch and their interactions (including interaction with seed rates) showed none significant effect on grain yield, biomass, straw yield and frost scores of faba bean. However, interaction of faba bean seed rate with potash and mulch had significant effect ($p<0.05$) only on seed yield and number of pods per plant of faba bean, respectively (DBARC, 2003). The above experiment was executed for two cropping seasons using lower rates of KCl (0 and 25 kg KCl/ha). In addition to this, frost had occurred at latter stage of grain filling and couldn't affect the yield satisfactorily. Hence, this experiment was initiated to evaluate the effect of some agronomic and nutrient management options such as variety and potassium application in staggered sowing dates to increase probability of discrimination.

Objective: to evaluate the effect of sowing date, variety and potassium against frost in faba bean

2. MATERIALS AND METHODS

2.1 Description of experimental site

The experiment was conducted at Debre birehan research center main station (Faji) during the main rainy seasons of 2017 and 2018 from July to December. Geographically the area is located at latitude of $9^0$36′07.8″ N, longitude of 39^{03}30′02.4″E and altitude of 2820 meters above sea level (INFO ARARI, 2004).

2.2 Treatments, experimental design and procedures

The treatments included factorial combination of two of sowing dates (farmers practice, after 2-3 weeks from first sowing), two varieties of faba bean (Wolki and Dagim - large and small seed size, respectively) and four levels of potash (0, 50, 100 and 150 Kg K_2O/ha) in randomized complete block design with three replications. Potassium chloride (KCl) was used as a source of potash fertilizer. The gross plot size of 8 m^2 (2 m wide and 4 m long) was used. Space between replications and plots was maintained at 1.5 m and 40 cm, respectively. Handmade broad bed and furrow (traditionally used by farmers) drainage system was implemented. In this practice, 80cm wide soil beds (raised beds) separated by 40 cm wide furrows for drainage, with beds approximately 15 cm high were prepared. Row planting was done on a raised bed condition. The whole KCl, depending on the potash levels was drilled in rows during sowing in the first year while two splits (half during sowing and half at early pod setting stage) was drilled in the second year. In addition to KCl, NPS chemical fertilizer at the rate of 121 kg/ha was applied uniformly for all experimental plots uniformly. The whole plot (4 rows on two beds) was considered for agronomic data collection and grain yield measurement. Other pests (diseases and insects) were managed using pesticides to minimize confounding effect with frost injury. Two times hand weeding was undertaken to control weeds.

2.3 Data collection, measurement and analysis

Data on plant height, number of pods per plant and number of seeds per pod was measured from 10 randomly selected plants from each plot. Days to flowering was recorded when 50% of the plants in a plot produced their first flower. Frost injury was scored visually using one to nine scales after frost incidence in mid-seed filling stage (frost occurred late in the season in both years). Stand count at harvest was taken from the whole plot while harvesting. Grain yield was measured in grams from the whole plot (four rows) and converted into kg per hectare while 100 seeds weight was measured in grams for randomly counted 100 seed samples from each plot. Germination test was done after harvest by taking four random samples (a total of 100 seeds) from each plot.

About one kg composite soil sample was collected from the whole plot (from five spots) in a zigzag pattern to the depth of 0-30 cm at time of sowing for determining textural class (particle size), soil reaction (pH), organic matter, total N, available P, exchangeable K. Textural class was analyzed using hydrometer method as stated by Hazelton and Murphy (2007), soil reaction (pH) was tested using potentiometric method described by Murphy (1968), organic matter was determined using Walkley and Black method as stated by Tekalign (1991), Total N was determined following modified Kjeldahl method described by Tekalign (1991), available P was determined using Olson's method described by Cottenie (1980), exchangeable K was determined by flame photometer described by FAO (2006).

Unpublished secondary daily minimum temperature data obtained from Debre Birhan agricultural research center and national metrology agency station at Debre Birhan town was used to interpret frost hazard.

Data were subjected to the analysis of variance (ANOVA) following the statistical procedure for three factors factorial experiments using SAS Software version 9.0, 2002. Mean comparison was performed using Duncan's Multiple Range Test (DMRT) at 5% level of significance upon obtaining significant F-values of the factors and interactions. Two years data was combined up on obtaining variance homogeneity, which was tested by employing Bartlett's test. In 2018, 2nd sowing was affected by Porcupine damage. Therefore, stand count at harvest was considered as a covariate while analyzing grain yield.

Economic analysis was performed on mean grain yield following the partial budget analysis method of CIMMYT (1988). The field price was obtained by simple assessment of farm gate prices near experimental field after harvest (January - February) which was taken as average of the two years. Accordingly, the prices of grain yield of Wolki and Dagm faba bean varieties found to be Ethiopian Birr (ETB) 23 and 20 kg/ha, respectively. The variable costs included cost of potassium chloride (KCl) and estimated to be ETB 13.50 kg/ha. The average yield was adjusted downward to 10% assuming yield reduction by 10% if farmers manage the same on larger plot. In order to use marginal rate of return (MRR) as a basis for sowing date, variety and potash recommendation, the minimum acceptable rate of return was set at 100% (CIMMYT, 1988). Treatments that have higher costs that vary but lower net benefit than treatments of lower cost with higher net benefit were considered to be dominated and were eliminated from further consideration.

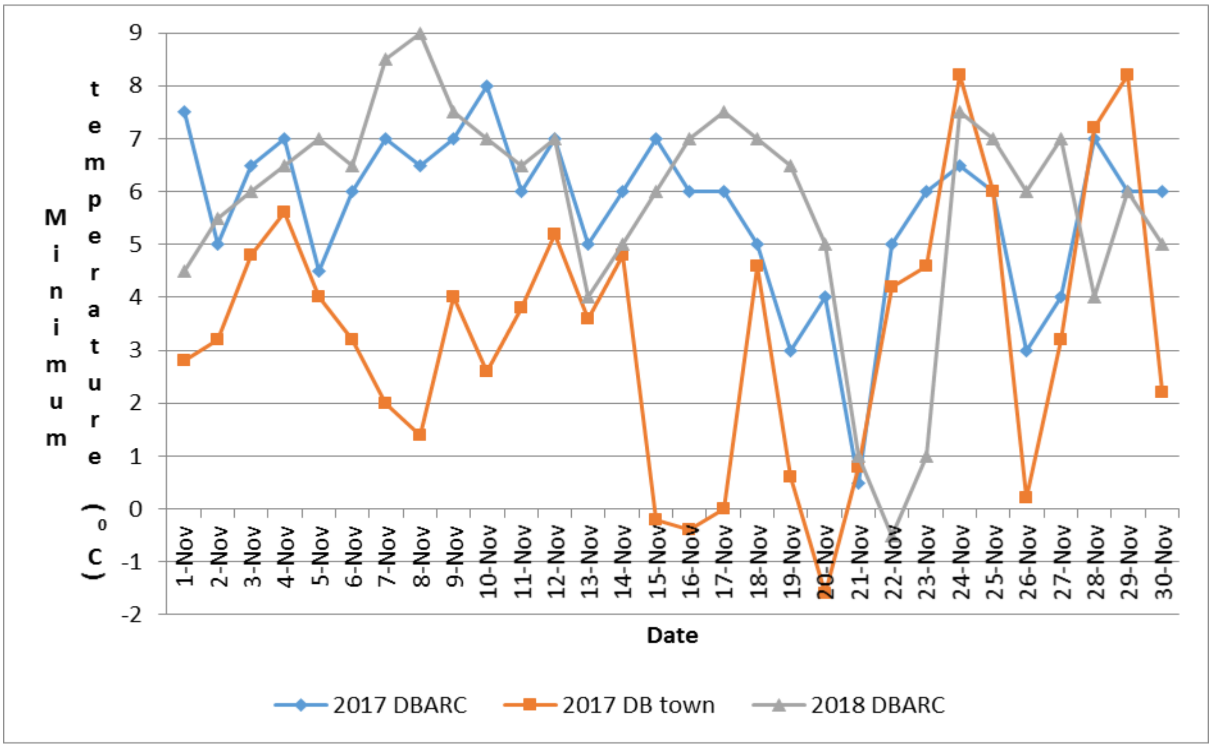
3. RESULTS AND DISCUSSION

3.1 Soil physico-chemical properties of the experimental site

The soil analysis of the study site (averaged over two years) revealed that the surface soil of the experimental field was medium clay (47%) in texture, moderately acidic in pH (5.55), moderate in organic matter (3.68%), moderate in total nitrogen content (0.18%), very low in available phosphorus (4.05 mg/kg), medium in exchangeable potassium [0.43 cmol(+)/ kg soil] (Soil lab results from Debre Brehan agricultural research center, 2017-2018). According to the soil analysis results, potassium in the soil was in the medium range that might not satisfy the high level of potassium required to increase solute concentration and lower the freezing point of water in the plant tissue (Waraich *et al*., 2012). In other words, continuous supply of potassium at a much higher concentration in the soil solution than that regarded as "sufficient" for maximum yield might prove as an "insurance" against unexpected climatic events (Kant and Kafkafi, n.d.).

3.2 Minimum temperature conditions for crop growth period

Unpublished daily minimum temperature data obtained from Debre Birhan Agricultural Research Center (DBARC) and national metrology agency station at Debre Birhan town (DB town) was used to interpret incidence of frost though the data is not available for DB town for the year 2018 (Fig. 1). In 2017, record for the daily minimum temperature was a little bit higher at DBARC which raised a reliability issue. Hence, data obtained from DB town (10 km far from DBARC) could be used side-by-side to interpret the result. In 2017, the temperature for DB town was lower than DBARC from 1st November to 20th November. During this period, the temperature approached and/or sometimes below 0^{0}C at DB town while it was above 3^{0}C at DBARC. In 2017 frost score was made on 15th November while the temperature at DBARC was not below 4^{0}C, but it was around 1.4^{0}C at DB town. In 2018 frost score was made in 23rd of November while the temperature was below 0^{0}C for some days at DBARC. In general, the minimum temperature was inconsistent from day to day in both years in both localities (Fig. 1).



DBARC=Debre Birhan Agricultural Research Center, DB town=Debre Birhan Town

Figure 1: Minimum temperature data for November (2017 and 2018)

3.3 Biological data

Separate and combined analysis of the two years (2017 and 2018) data was performed to interpret the results independently as well as to see their combined effect over years. Accordingly, in 2017 frost injury was significantly influenced by variety by K_2O interaction while germination percentage was significantly influenced by sowing date by K_2O interaction (Table 1). In 2018 number of pods per plant, plant height and hundred seeds weight were significantly influenced by variety by K_2O interaction while grain yield was significantly influenced by three-way interaction of sowing date by variety by K_2O interaction which was probably due to split application of potassium (Table 2). In combined analysis none of the interactions with K_2O were significant (Table 3). On the other hand, sowing date and variety showed significant effect on most parameters considered. Parameters and interactions that had significant effects at $P<0.05$ are presented below giving more focus for the interactions occurred with potash.

3.3.1 Days to 50% flowering

Sowing date showed significant ($P<0.05$) effect on days to flowering in both years (2017 and 2018). Since frost occurred late in the season (in mid-seed filling stage), flowers were not affected by frost injury in both sowing dates in both years.

However, there was variation in response from year to year showing longer date of flowering in the second year for first sowing date (Table 1 and 2). In similar results, Pandey (1981; as cited in Manning, 2017) noted that especially in the second year, longer days to flowering were recorded for the first sowing date probably due to colder days that lengthened time to flower in early sown crops and delayed sowing shortened the period to first flower. Manning (2017) reported decreasing trend in flowering from first sowing date to third sowing date. On the other hand, Adisarwanto and Knight (1997; as cited in Manning, 2017) found no such relationship possibly because their work did not encompass a wide enough range of sowing dates. Variety 'Wolki' flowered significantly (P<0.05) earlier than 'Dagm' probably related to genotypic effect (Tables 1-3). In agreement with this result, Salem (2007) reported presence of significant difference in flowering between medium- and large seeded faba bean varieties.

3.3.2 Plant height

Plant height significantly (P<0.05) affected by sowing date in both years and combined over years. Shortest plants were measured from second sowing date that might be due to shorter growth period which enhanced maturity due to competition for moisture (Tables 1-3). In line with this result, Megawer *et al*. (2017) reported that early sowing date (22nd October) caused significant increases in plant height (43.35%) compared with delaying sowing date (22nd November). Similarly, plant height significantly (P<0.05) influenced by variety in both years and combined over years. Among the varieties tested, the tallest plants were measured from variety 'Wolki' while the shortest were under variety 'Dagm' (Tables 1-3). Yucel (2013) obtained significant differences among genotypes in terms of plant height of faba bean crop. On the other hand, in 2018 plant height was significantly (P<0.05) affected by variety by potash (K_2O) interaction (Table 2). Accordingly, for variety 'Wolki' relatively tallest plant height was recorded under K_2O level of 0 kg/ha while for variety 'Dagm' it was under K_2O level of 150 kg/ha (Table 5).

3.3.3 Number of pods per plant

Sowing date showed significant (P < 0.05) effect on number of pods per plant in both years and combined over years. First sowing date produced highest number of pods per plant (Tables 1-3) probably due to shorter growth period in the second sowing date that might shorten production of many pods. Tawaha and Turk (2001a) noted that the delay in faba bean sowing date resulted in fewer pod probably due to shorter growing period that resulted in reduced seed yield (though not related to frost). In 2018 variety by K_2O interaction showed significant (P < 0.05) effect on number of pods per plant (Table 2). Accordingly, for variety 'Wolki' relatively highest number of pods per plant was recorded under K_2O level of 0 kg/ha while for variety 'Dagm' it was under K_2O level of 150 kg/ha (Table 5).

3.3.4 Number of seeds per pod

In 2017 potash showed significant (P< 0.05) effect on number of seeds per pod (Table 1). The highest number of seeds per pod was obtained from the highest potash level (150 kg/ha) as it has a positive role in increasing the grain number. Review made by Hasanuzzaman *et al*. (2018) reported highest number of grains from the highest potassium level in wheat. According to these authors, the higher amount of K helps to transfer food material to develop grains, thus decreasing the amount of sterile grain. In similar review, in Boro rice (O. sativa) when the K was applied at 100 kg ha^{-1} the grain sterility was lower compared to the treatment with no K application (at 100 kg K ha^{-1} the grain sterility was 22.60%, whereas without K, it was 30.33%) (Hasanuzzaman *et al*., 2018). In 2018 and combined over years, variety showed significant (P< 0.05) effect on number of seeds per pod (Tables 2-3). Accordingly, variety 'Dagm' produced highest number of seeds per pod than 'Wolki' (Tables 2 and 3) probably related to genotypic effect. In line with this result, Bakry *et al*. (2011) reported significant effect of cultivars of faba bean crop on number of seeds per pod.

3.3.5 Hundred seeds weight

As indicated in Table 1, in 2017 significantly (P<0.05) the lowest hundred seeds weight was recorded from second sowing date in both years and combined over years probably due to less dry matter accumulation and effect of frost on the second sowing date (Table 1-3). In agreement with this result, Tawaha and Turk (2001a) noted that the delay in faba bean sowing date greatly reduced 100 seeds weight probably due to shorter growing period that might result in less dry matter accumulated which in turn result in reduced seed yield. Similarly, Megawer *et al*. (2017) noted that early sowing date (22nd October) caused significant increases in 100 seed weight (2.69%) compared with delaying sowing date (22nd November). Similarly, in 2017 significantly (P<0.05) heaviest hundred seeds weight was recorded from K_2O level of 50 kg/ha though not significantly different from 100 kg/ha. The highest hundred seeds weight was obtained from large seeded variety 'Wolki' and the lowest from small seeded variety 'Dagm' in both years and combined over years (Table 1-3). The difference was probably related to genotypic variation which is related to seed size. In line with this result, Salem (2007) reported that large seeded faba bean cultivar 'Riena Blanca' produced the heaviest 100-seeds weight (96.4 g) among the six genotypes tested. As indicated by Yucel (2013), hundred seeds weight of faba bean reflects the ability of the genotypes to partition its dry matter into seed where small seeds develop rapidly once the reproductive phase starts, and produce less dry matter in their seed. Hence, due to decrease of assimilates, small seeds produce less seed weight. In 2018 variety by K_2O interaction showed significant ($P<0.05$) effect on hundred seeds weight (Table 2). Accordingly, for variety 'Wolki' relatively heaviest hundred seeds weight was recorded under K_2O level of 150 kg/ha while it was under 50 kg/ha for variety 'Dagm' (Table 5).

3.3.6 Frost injury

Frost occurred late in the season in November in both years while first sowing was in later grain filling stage and second sowing was in mid grain filling stage. In 2017, frost score was made on 15th November while minimum temperature was not lower than 4.5^{0}C (on 5th November) at DBARC though it was around -0.2^{0}C (on 15th November) at DB town (Fig. 1). On the other hand, in 2018 frost score was done on 23rd of November while minimum temperate was around -0.5^{0}C (on 22nd November) at DBARC (Fig. 1). As stated by Reddick (2009), frost can sometimes form even if air temperatures are above freezing which is referred to as "radiation frost". On other words, ''radiation frost is common during cloudless night, ice crystals may form on plants and other objects when their surface temperature drops below freezing and sufficient moisture is in the air, but the actual air temperatures remain above freezing''.

Sowing date showed significant ($P<0.05$) effect on frost injury in both years and combined over years (Table 1-3) while variety and variety by K_2O interaction showed significant ($P<0.05$) effect on frost injury in 2017 (Table 1). At time of scoring, older (lower) pods in the first sowing date were at maturity stage which could able to escape frost injury. However, according to visual score, leaves in the first sowing were more sensitive to frost incidence than second sowing which was probably due to aging problem as older leaves became more sensitive to frost than younger ones. In opposite to this result, Reddick (2009) noted that older more mature plants can typically tolerate freezing temperatures better than juvenile plants. In 2017 small seeded variety 'Dagm' seemed more tolerant/healthier than large seeded variety 'Wolki' and scored lower frost injury (Table 1). In 2017 though not significantly different from other levels, variety 'Wolki' scored lowest frost injury at K_2O level of 50 kg/ha while variety 'Dagm' at K_2O level of 0 kg/ha (Table 4).

3.3.7 Germination efficiency

A germination test was done after harvest to determines the percentage of seeds that are alive after frost injury. Accordingly, sowing date showed significant ($P<0.05$) effect on germination efficiency in both years and combined over years. Highest germination efficiency was obtained for first sowing date probably due to escape of lower pods/seeds before frost occurrence (Table 1-3). On the other hand, variety showed significant ($P<0.05$) effect on germination efficiency in 2017 and combined over years. Variety 'Wolki' showed higher germination efficiency than 'Dagm' in all years probably due to earliness in maturity of lower pods (maturity data not available due to confounding effect of frost injury) (Table 1-3). K_2O showed significant ($P<0.05$) effect on germination efficiency in 2017. Accordingly, the highest germination efficiency was recorded under highest level of K_2O (150 kg K_2O/ha) (Table 1) as K_2O assists in seed germination by initiating the rapid imbibition of water (Farooq *et al.*, 2008). Sowing date by K_2O interaction showed significant ($P<0.05$) effect on germination efficiency in 2017. First sowing date showed highest germination efficiency at K_2O level of 100 kg/ha while second sowing date at K_2O level of 150 kg/ha (Table 4).

3.3.8 Grain yield

As indicated in Tables 1-3, sowing date showed significant ($P<0.05$) effect on grain yield in both years and combined over years. The highest grain yield was obtained from first sowing date probably due to longer growth period for the crop to have well developed yield components that can contribute to higher grain yield in the early sowing date. Similarly, there was better chance to escape late coming frost and produce higher yield. For example, highest number of pods per plant and heaviest 100 seeds weight was obtained from first sowing which could give highest and heaviest seeds than second sowing. According to Megawer *et al.* (2017) seed yield of faba bean was influenced significantly by sowing date and the maximum seed yield was obtained from early sowing due to shorter growth period at the disposal of the late sown crop as the time taken by the crop to mature decreased with delay in sowing. Similarly, review made by Manning (2017) noted that earlier sowing increased the length of the flowering and pod filling phase which contributed to higher yield through greater pod number and greater seed weight.

Variety showed significant (P<0.05) effect on grain yield in both years. Among the varieties tested, highest grain yield was obtained for variety 'Wolki' (Table 1 and 2) though it seemed non-significant for combined over years while using year by variety interaction as an error term (Table 3). The highest grain yield produced by variety 'Wolki' might be attributed to genotypic effect. On the other hand, three-way interaction of sowing date by variety by K_2O showed significant (P<0.05) effect on grain yield in 2018 (Table 2). Accordingly, for both varieties the highest grain yield was obtained in the first sowing date at K_2O level of 50 and 0 kg/ha for 'Wolki' and 'Dagm', respectively. In the second sowing date the highest grain yield for variety 'Wolki' and 'Dagm' was obtained at K_2O level of 100 and 150 kg/ha, respectively (Table 6).

Table 1: Main effects of agronomic and nutrient management options on grain yield and some parameters of faba bean at Faji in 2017

Treatments	DTF	Plh (cm)	NPPP	NSPP	HSW (g)	FI (%)	GE (%)	GY (t/ha)
Sowing date (Sd)								
1	53.5[b]	122.3[a]	15.4[a]	2.4	36.98[a]	51.97[a]	61.88 (4.09)[a]	3.47[a]
2	54.1[a]	101.6[b]	12.8[b]	2.3	29.52[b]	27.28[b]	31.88 (3.22)[b]	1.78[b]
F-test	**	**	**	ns	**	**	**	**
Variety (V)								
Wolki (Large seeded)	52.1[b]	118.6[a]	14.2	2.3	40.63[a]	48.50[a]	55.83 (3.95)[a]	3.14[a]
Dagm (Small seeded)	55.5[a]	105.3[b]	14.0	2.4	25.87[b]	30.75[b]	37.92 (3.36)[b]	2.11[b]
F-test	**	**	ns	ns	**	**	**	**
Potash (K_2O kg/ha)								
0	53.8	112.4	13.9	2.3[ab]	32.67[b]	39.55	39.58 (3.54)[b]	2.58
50	53.7	115.8	14.5	2.2[b]	34.50[a]	39.59	47.92 (3.68)[ab]	2.76
100	53.8	111.4	14.6	2.4[ab]	33.68[ab]	38.77	45.83 (3.46)[ab]	2.64
150	53.8	108.3	13.3	2.5[a]	32.14[b]	40.59	54.17 (3.95)[a]	2.52
F-test	ns	ns	ns	*	*	ns	*	ns
Mean	53.8	112.0	14.1	2.4	33.25	39.63	3.66	2.63
Sd*K_2O	ns	ns	ns	ns	ns	ns	**	ns
V*K_2O	ns	ns	ns	ns	ns	*	ns	ns
Sd*V*K_2O	ns	ns	ns	ns	ns	ns	ns	ns
CV (%)	1.14	8.93	17.56	9.72	5.77	13.83	10.02	12.64

DTF=Days to 50% flower, NPPP=Number of pods per plant, NSPP=Number of seeds per pod, Plh=Plant height HSW=Hundred seeds weight, FI=Frost injury, GE=Germination efficiency, GY=Grain yield, CV= coefficient of variation, Means in column followed by the same letters are not significantly different at 5% level of significance

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Table 2: Main effects of agronomic and nutrient management options on grain yield and some agronomic parameters of faba bean at Faji in 2018

Treatments	DTF	Plh (cm)	NPPP	NSPP	HSW (g)	FI (%)	GE (%)	Grain yield (t/ha) Observed	Grain yield (t/ha) Adjusted
Sowing date (Sd)									
1	57.9[a]	125.4[a]	15.6[a]	2.6	41.64[a]	73.78[a]	72.50 (4.27) [a]	3.76[a]	3.75[a]
2	55.0[b]	103.1[b]	14.2[b]	2.5	33.60[b]	43.20[b]	51.39 (3.84) [b]	1.40[b]	1.42[b]
F-test	**	**	*	ns	**	**	**	**	**
Variety (V)									
Wolki (Large seeded)	55.3[b]	120.9[a]	15.3	2.4[b]	44.38[a]	58.86	66.94(4.16)	2.90[a]	2.92[a]
Dagm (Small seeded)	57.6[a]	107.5[b]	14.5	2.6[a]	30.86[b]	58.13	56.94(3.95)	2.27[b]	2.25[b]
F-test	**	**	ns	**	**	ns	ns	**	**
Potash (K_2O kg/ha)									
0	56.4	112.9	15.2	2.6	37.5	58.2	58.89(4.00)	2.59	2.59
50	56.4	113.4	15.1	2.5	37.71	57.12	62.22(4.05)	2.66	2.66
100	56.5	113.4	14.5	2.4	37.04	55.45	66.11(4.15)	2.41	2.41
150	56.5	117.2	14.6	2.5	38.24	63.2	60.55(4.01)	2.67	2.67
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns
Mean	56.5	114.2	14.9	2.5	37.62	58.5	4.05	2.6	2.58
Sd*K_2O	ns	ns	ns	ns	ns	ns	ns	ns	ns
V*K_2O	ns	*	*	ns	*	ns	ns	ns	ns
Sd*V*K_2O	ns	ns	ns	ns	ns	ns	ns	*	*
Covariate									ns
CV (%)	0.85	4.56	14.39	8.3	5.6	14.46	10.6	11.7	11

DTF=Days to 50% flower, NPPP=Number of pods per plant, NSPP=Number of seeds per pod, Plh=Plant height HSW=Hundred seeds weight, FI=Frost injury, GE=Germination efficiency, GY=Grain yield**,** CV= coefficient of variation

Table 3: Main effects of agronomic and nutrient management options on grain yield and some agronomic parameters of faba bean at Faji, combined over years (2017-2018)

Treatments	DTF	Plh (cm)	NPPP	NSPP	HSW (g)	FI (%)	GE (%)	Grain yield (t/ha) Observed	Grain yield (t/ha) Adjusted
Sowing date (Sd)									
1	54.2	123.8[a]	15.4[a]	2.5	39.3[a]	62.87[a]	67.18(4.18)[a]	3.61[a]	3.61[a]
2	56.0	102.3[b]	13.5[b]	2.4	31.6[b]	35.24[b]	41.63(3.53)[b]	1.56[b]	1.59[b]
F-test	ns	**	**	ns	**	**	**	**	*
Variety (V)									
Wolki (Large seeded)	53.7	119.7[a]	14.7	2.4	42.51[a]	53.68	61.39(4.06)[a]	3.02	3.02
Dagm (Small seeded)	56.5	106.4[b]	14.2	2.5	28.37[b]	44.43	47.43(3.65)b	2.19	2.19
F-test	ns	**	ns	*	**	ns	**	ns	ns
Potash (K_2O kg/ha)									
0	55.1	112.6	14.6	2.5	35.09	48.87	49.24(3.77)	2.59	2.59
50	55.0	114.6	14.8	2.4	36.11	48.35	55.07(3.87)	2.71	2.71
100	55.2	112.4	14.6	2.4	35.36	47.11	55.97(3.80)	2.53	2.53
150	55.1	112.7	14.0	2.5	35.19	51.90	57.36(3.98)	2.59	2.59
F-test	ns	ns	ns	ns	ns	ns	ns	ns	ns

Mean	55.1	113.1	14.5	2.4	35.44	49.06	54.41(3.85)	2.60	2.60
Sd*K_2O	ns	ns	ns	ns	ns	ns	ns	ns	ns
V*K_2O	ns	ns	ns	ns	ns	ns	ns	ns	ns
Sd*V*K_2O	ns	ns	ns	ns	ns	ns	ns	ns	ns
Covariate									ns
CV (%)	1.00	7.05	15.97	8.99	5.69	14.52	10.36	11.80	11.87

F test for main effects was performed by using significant year by factor interaction as a denominator; otherwise, the pooled error mean square is used as a denominator. DTF=Days to 50% flower, NPPP=Number of pods per plant, NSPP=Number of seeds per pod, Plh=Plant height HSW=Hundred seeds weight, FI=Frost injury, GE=Germination efficiency, GY=Grain yield, CV= coefficient of variation

Table 4: Interaction effect of variety and potash on frost injury and potash and sowing date on germination efficiency of faba bean in 2017

K_2O (kg/ha)	Frost injury (%)		Germination efficiency (%)	
	Variety		Sowing date	
	Wolki	Dagm	1	2
0	50.7^{a}	28.4^{b}	$48.33 (3.85)^{b}$	$30.83 (3.22)^{cd}$
50	44.85^{a}	34.33^{b}	$66.67 (4.17)^{a}$	$29.17 (3.20)^{cd}$
100	46.97^{a}	30.57^{b}	$70.00 (4.23)^{a}$	$21.67 (2.69)^{d}$
150	51.50^{a}	29.68^{b}	$62.50 (4.13)^{ab}$	$45.83 (3.77)^{bc}$

Means in column followed by the same letters are not significantly different at 5% level of significance

Table 5: Interaction effect of variety and potash on number of pods per plant, plant height and hundred seeds weight of faba bean in 2018

	NPPP		Plh (cm)		HSW (g)	
	Variety					
K_2O (kg/ha)	Wolki	Dagm	Wolki	Dagm	Wolki	Dagm
0	16.5^{a}	13.8^{ab}	123.5^{a}	102.3^{d}	44.86^{a}	30.13^{bc}
50	15.3^{ab}	15.0^{ab}	117.4^{ab}	109.4^{c}	42.83^{a}	32.60^{b}
100	15.7^{ab}	13.2^{b}	120.8^{a}	106.0^{cd}	44.48^{a}	29.60^{c}
150	13.5^{b}	15.8^{ab}	122.0^{a}	112.4^{bc}	45.35^{a}	31.13^{bc}

Means in column followed by the same letters are not significantly different at 5% level of significance

Table 6: Interaction effect of sowing date by variety by potash on grain yield of faba bean in 2018

Treatment combination			Adjusted grain yield (t/ha)
Sowing date	Variety	K_2O (kg/ha)	
1	Wolki	**0**	4.37^{ab}
1	Wolki	50	4.75^{a}
1	Wolki	100	4.15^{b}
1	Wolki	150	4.37^{ab}
2	Wolki	**0**	1.48^{de}
2	Wolki	50	1.41^{de}
2	Wolki	100	1.49^{de}
2	Wolki	150	1.34^{de}

1	Dagm	**0**	3.34[c]
1	Dagm	50	2.92[c]
1	Dagm	100	2.86[c]
1	Dagm	150	3.21[c]
2	Dagm	**0**	1.17[e]
2	Dagm	50	1.57[de]
2	Dagm	100	1.13[e]
2	Dagm	150	1.78[d]
Mean			2.58
CV (%)			11.00

CV= coefficient of variation, means in column followed by the same letters are not significantly different at 5% level of significance

3.4 Economic analysis

Economic analysis was performed on mean grain yield obtained from three-way interaction in 2018 and combined mean over years (though there was no significant difference) to see if there exists difference between combined mean and separate mean for 2018 based on CIMMYT (1988). Accordingly, the highest net benefit (ETB 97200.05 and 92646.05) with marginal rate of return of 599.23% and 323.22% was obtained for variety 'Wolki' in the first sowing date at K_2O level of 50 kg/ha in 2018 and combined over years, respectively (Tables 7 and 8). On the other hand, use of K_2O might not be feasible for small seeded variety 'Dagm', especially in the first sowing date.

Table 7: Dominance and marginal rate of return analysis for the effect of date of sowing by variety by potash on grain yield (t/ha) of faba bean at Faji in 2018

Treatment combination				Grain yield (t/ha)					
Sowing date	Variety	K_2O (kg/ha)	Rate of KCl (kg/ha)	Observed	adjusted (10% down)	GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
1	Wolki	0	0	4.37	3.93	90459.00	0.00	90459.00	
2	Wolki	0	0	1.48	1.33	30636.00	0.00	30636.00	D
1	Dagm	0	0	3.34	3.01	60120.00	0.00	60120.00	D
2	Dagm	0	0	1.17	1.05	21060.00	0.00	21060.00	D
1	Wolki	50	83.33	4.75	4.28	98325.00	1124.96	97200.05	599.23
2	Wolki	50	83.33	1.41	1.27	29187.00	1124.96	28062.05	D
1	Dagm	50	83.33	2.92	2.63	52560.00	1124.96	51435.05	D
2	Dagm	50	83.33	1.57	1.41	28260.00	1124.96	27135.05	D
1	Wolki	100	166.67	4.15	3.74	85905.00	2250.05	83654.96	D
2	Wolki	100	166.67	1.49	1.34	30843.00	2250.05	28592.96	D
1	Dagm	100	166.67	2.86	2.57	51480.00	2250.05	49229.96	D
2	Dagm	100	166.67	1.13	1.02	20340.00	2250.05	18089.96	D
1	Wolki	150	250.00	4.37	3.93	90459.00	3375.00	87084.00	D
2	Wolki	150	250.00	1.34	1.21	27738.00	3375.00	24363.00	D
1	Dagm	150	250.00	3.21	2.89	57780.00	3375.00	54405.00	D
2	Dagm	150	250.00	1.78	1.60	32040.00	3375.00	28665.00	D

K_2O=Potash, KCl=Potassium chloride, GB=Gross benefit, TVC=Total variable cost, NB=Net benefits, MRR= Marginal rate of return, D= Dominated

Table 8: Dominance and marginal rate of return analysis for the effect of date of sowing by variety by potash on grain yield (t/ha) of faba bean at Faji, combined over years (2017 and 2018)

Treatment combination				Grain yield (t/ha)		GB (Birr/ha)	TVC (Birr/ha)	NB (Birr/ha)	MRR (%)
Sowing date	Variety	K_2O (kg/ha)	Rate of KCl (kg/ha)	Observed	adjusted (10% down)				
1	Wolki	0	0	4.30	3.87	89010.00	0.00	89010.00	
2	Wolki	0	0	1.72	1.55	35604.00	0.00	35604.00	D
1	Dagm	0	0	3.02	2.72	54360.00	0.00	54360.00	D
2	Dagm	0	0	1.31	1.18	23580.00	0.00	23580.00	D
1	Wolki	50	83.33	4.53	4.08	93771.00	1124.96	92646.05	323.22
2	Wolki	50	83.33	1.89	1.70	39123.00	1124.96	37998.05	D
1	Dagm	50	83.33	2.99	2.69	53820.00	1124.96	52695.05	D
2	Dagm	50	83.33	1.43	1.29	25740.00	1124.96	24615.05	D
1	Wolki	100	166.67	4.02	3.62	83214.00	2250.05	80963.96	D
2	Wolki	100	166.67	1.89	1.70	39123.00	2250.05	36872.96	D
1	Dagm	100	166.67	2.90	2.61	52200.00	2250.05	49949.96	D
2	Dagm	100	166.67	1.31	1.18	23580.00	2250.05	21329.96	D
1	Wolki	150	250.00	4.23	3.81	87561.00	3375.00	84186.00	D
2	Wolki	150	250.00	1.60	1.44	33120.00	3375.00	29745.00	D
1	Dagm	150	250.00	2.94	2.65	52920.00	3375.00	49545.00	D
2	Dagm	150	250.00	1.61	1.45	28980.00	3375.00	25605.00	D

K_2O=Potash, KCl=Potassium chloride, GB=Gross benefit, TVC=Total variable cost, NB=Net benefits, MRR= Marginal rate of return, D= Dominated

4. CONCLUSION

This study indicated that early sowing and variety could contribute more for frost protection than K_2O application. Large seeded variety 'Wolki' found more responsive to application of K_2O than small seeded variety 'Dagm'. According to ANOVA and economic analysis results K_2O at the rate of 50 kg/ha found economically optimum for variety 'Wolki' at first/early sowing as highest grain yield and lowest frost injury was obtained at this level. Hence, time of split application of this level should be further studied. On the other hand, application of K_2O showed no significant contribution for the small seeded variety 'Dagm'. Accordingly, early sowing/escaping mechanism found better option than frost resistance/tolerance. In case of early frost occurrence (though time of frost occurrence could not be predicted), use of potassium might be considered as an option for the small seeded variety too.

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