EFFECTIVE NUMBER AND SEED PRODUCTION IN A CLONAL SEED ORCHARD OF *PINUS KORAIENSIS*[1]

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ABSTRACT

Theory on the tradeoff between effective number and seed production was applied to a clonal seed orchard of *Pinus koraiensis* in Korea. By controlling maternal fertility, a balancing between equalizing maternal contribution and obtaining an acceptable amount of seed was achieved. Constrains on seed production was made on the maternal proportion as both lower and upper bounds. For maternal gametes in the seed orchard of *P. koraiensis* (180 clones), the effective number of parent (N_p) was estimated to 132.1 clones (73% of census number, N) based on the average observation of 9 years. For the level of clone, N_p was estimated to 66.8 clones (37 % of census number) if all seeds were collected and used. Higher effective number of parents could be obtained by balancing the number of seeds collected per clone, but such increase of the effective number would result in substantial loss of seed production. If it was decided to truncate the seed production from 90% of census number and to collect the equal amount of seed from the best 10% clones, this increased the effective number from 132.1 to 143.7 and the loss of seed production would be 5.5%.

Key words: effective number, equal collection, fertility balancing, Korean pine

INTRODUCTION

In Korea, 300 plus-trees of *Pinus koraiensis* S. et Z. have been selected since 1959 and the total 94 ha of seed orchards have been established since 1968. From the seed orchards, we have produced 72 tons of genetically improved seeds. It has been reported that clones show a large variation in fertility. Some clones in a seed orchard carry a lot of seed, while the rest of the clones carry seed to varying degree, and sometimes a few clones don't produce any seed. This variation in maternal fertility is a general feature observed in almost all seed orchards (KANG 2001).

The variation in fertility means that orchard clones contribute differently to the collected seed crop. It results in unequal representation of the parent genotypes in seed production, and thereby in the seedlings raised from the seed collections. The degree of relatedness in the progenies will be increased when compared to the situation where all parental clones have equal fertility. It has an implication in terms of sampled genetic diversity because genetic drift is increased with unequal contribution of gametes (CROW & KIMURA, 1970; POLLAK, 1977). The fertility variation can be quantified by a measure of effective population number (CROW & KIMURA, 1970; KANG & LINDGREN, 1999). Knowing pedigree, the status number (N_s) can be calculated from the relatedness of parental genotypes (LINDGREN *et al.*, 1996; LINDGREN &MULLIN, 1998).

Keeping maternal contribution equally by collecting seeds in equal proportions from each tree was suggested by BILA (2000), KANG and EL-KASSABY (2002) and KANG *et al.* (2001). But, equal contribution will require substantial loss of seed production because least fertile clones will set the standard of constrain (KANG *et al.* 2003). If seed demand would be high, complete equal maternal contribution is not a feasible option in many practical situations. Harvesting clones with few cones may be expensive and only contribute little to fertility variation. Constrain on the contribution of clones bearing many cones can increase gene diversity in the seed crop effectively, but may also reduce the

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contribution and obtaining an acceptable amount of seed (KANG *et al.*, 2003).

In the present study, quantitative tools for lower and upper constraints on maternal proportion selected are applied (1) to illuminate the quantitative importance of fertility control and (2) to give a ground for a proper allocation of efforts for balanced seed collection in a seed orchard of *Pinus koraiensis*.

MATERIALS AND METHODS

Flowering assessment

The clonal seed orchard of *Pinus koraiensis* S. et Z. is located at latitude 36° 30'N, longitude 126° 20'E in Suwon, Republic of Korea, and consisted of 180 genotypes. Trees originated from selected plus-trees over all the distribution area of Korea. They were propagated by grafting, and planted with the equal number of six ramets. It was established in 1983. For each tree in the population, the numbers of female and male strobili were counted for 9 years from 1991 through 1995, and from 1998 through 2001. Details of the population and data collection are given by KANG and LINDGREN (1999). We assumed that these initial 180 genotypes were unrelated and non-inbred and pollen contamination was negligible.

Fertility variation

The sibling coefficient (Ψ) was estimated (KANG & LINDGREN, 1999) as follows,

$$\psi = N\sum_{i=1}^{N} p_i^2 = 0.25\,CV^2 + 1$$

where N is the census number contributing to the gamete gene pool and p_i is the contribution of clone i, and CV is the coefficients of variation for seed production. For the separation between maternity and paternity, maternal (Ψ_m) and paternal (Ψ_p) fertility can be estimated based on the variation (CV_m and CV_p) of female and male strobilus production among clones as $\psi_m = 0.25\,CV_m^2 + 1$ and $\psi_p = 0.25\,CV_p^2 + 1$, respectively.

Effective number of parent

The effective number of parent (N_p) was calculated based on the sibling coefficient (Ψ) estimated for each of the nine years as follows,

$$N_p = \frac{N}{\Psi}$$

For relationship between census number (N) and effective number of parent (N_p), relative effective number (N_r) was calculated as N_p/N (KANG & LINDGREN 1998).

Balancing effective number and seed production

Two options for constrains on cone harvesting were investigated (KANG *et al.* 2003). The first option was not to harvest cones from the trees with the lowest number of cones (lower bound). These trees may be seen as too expensive to harvest. The second option was not to harvest more than a given number of seeds from each tree (upper bound); i.e., only a fixed number of cone was harvested from the trees with the high number of cones. Thus, no harvest was done from the lowest x_0 fraction of trees. On the other hand, an equal seed harvest was made on the highest fraction ($1-x_j$) of trees (see Fig. 1).

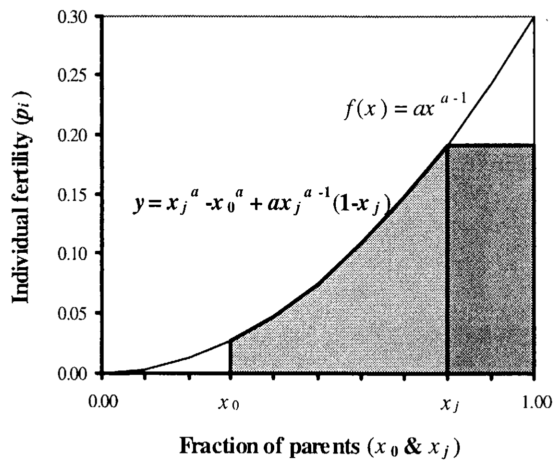

Figure 1. An example of expected individual fertility (p_i) and seed production (y) based on probability density power function, $f(x) = ax^{a-1}$ where a = 3. Grey colored area represents the relative cone production when the full potential of seed production is not used.

Balancing-1 is the seed collection from all clones, but the best 10% clones are collected by the equal amount of seeds (i.e., $x_0 = 0$ and $x_j = 0.9$). *Balancing-2* means that no harvest is done from the worst 20 % clones and the equal seed harvest is made from the top 20 % clones (i.e., x_0 = 0.2 and x_j = 0.8) for avoiding over-representation of the most fertile parents.

RESULTS AND DISCUSSION

There was a large variation in the production of strobilus production among clones and among years (Table 1). Maternal effective number was highest

Table 1. Average production of female strobili per graft, coefficient of variation (*CV*), sibling coefficient (*Y*), effective number (N_p) and relative effective number (N_r).

	1991	1992	1993	1995	1995	1998	1999	2000	2001
Average	2.3	3.7	8.2	5.9	3.6	5.4	13.2	8.8	0.9
CV	1.425	1.235	1.168	0.917	1.192	1.025	0.743	1.028	1.423
Ψ	.03	2.52	2.36	1.84	2.42	2.05	1.55	2.06	3.02
Np	59.4	71.3	76.1	97.7	74.3	87.8	116.0	87.5	59.5
Nr	0.33	0.40	0.42	0.54	0.41	0.49	0.64	0.49	0.33
r	–0.057	–0.030	0.103	0.035	–0.096	0.127	0.60	0.001	0.189

* correlation coefficient between female and male strobilus production.

when the production of female strobili was peak in 1999. But, this situation was opposite in the male effective number (data not shown). Fertility variation was larger when the average of gamete production was lower. N_r was ranged from 0.33 to 0.64, from 0.07 to 33 and from 18 to 45 at the levels of maternal gamete, paternal gamete and zygote, respectively. On average of 9 years, Y = 2.7, N_p = 66.8 and N_r = 0.37, respectively. The correlation between female and male strobilus production was weak and non-significant.

The slope of curve in Fig. 2 shows how additional clones increase the amount of seed and decrease the effective number. It was illustrated that adding increasingly fertile clones to seed production increased the effective number to a certain extend, but a few most fertile clones actually decreased the effective number. The top most fertile clones (6 clones, 4%) reduced the effective number from 136 to 132, which was not remarkable. In other words, the contribution of poorly flowering clones to N_p was bigger than their contribution to seed production. Increased effective numbers could thus be obtained when seed collection is made from all clones but equal seed harvest is done from the few most fertile clones (KANG *et al.* 2003).

Balancing-1 gave higher effective number than observation and *Balancing-2* while loss of seed production was 5.5% (Table 2). Constraint on the upper bound (x_j) was better for controlling fertility variation than that on the lower bound (x_0) in *P. koraiensis* (Fig. 3). Any genetic correlation between fertility and economic important traits (e.g., height, volume growth) means that balancing of fertility can have genetic implication on such desirable traits. In the case of *P. koraiensis* where Korean pine nut is

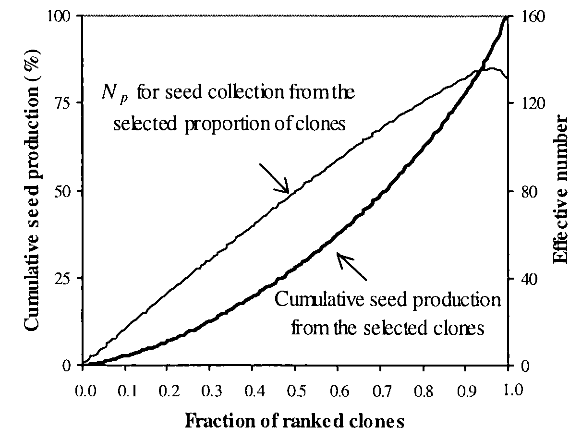

Figure 2. Cumulative seed production (%) and effective number (N_p) increasing additional fertile clones with ascending rank based on the pooled strobilus production over 9 years. The effective number decreased when a few most fertile clone were included.

one of the edible products, such potential correlation should be monitored in order to avoid negative selection.

Fertility variation occurs not only among seed

Table 2. Fertility coefficient of variation (*CV*), sibling coefficient (Ψ) and effective number (N_p) in the clonal seed orchard of *P. koraiensis*.

	Observation	Balancing-1	Balancing-2
CV	0.604	0.503	0.609
Ψ	1.36	1.25	1.37
N_p	131.9 (73.3)*	143.7 (79.8)	131.3 (72.9)
Seed loss (%)	0	5.5	16.3

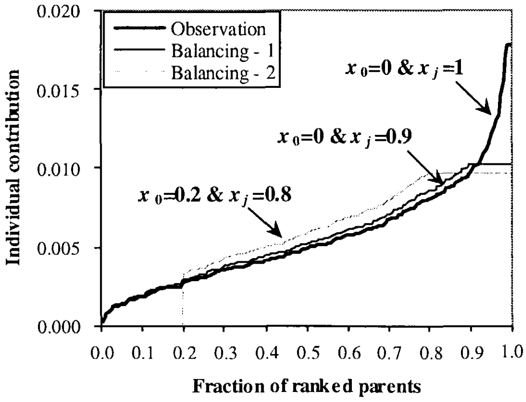

Figure 3. Control of maternal contribution for the tradeoff between effective number and seed production. Here, x_0 means a lower bound (minimum contribution) and x_j indicates an upper bound (maximum contribution; contribution limit). Thus, no harvest is done from the lowest x_0 fraction of clones. On the other hand, an equal seed harvest is made on the highest fraction ($1-x_j$) of clones to avoid over-representation of the most fertile parents.

parents but also among pollen parents. In this study, controlling on pollen parents was not included. Measurement and control of fertility variation of the pollen parents are usually difficult and inaccurate. There may be the decreased likelihood of retaining rare alleles present in the seed orchard by constraints on maternal contribution or by missing low fertility clones (e.g., *Balancing-2*). The number of alleles remaining after selection will be important for the long-term response, but heterozygosity may be kept independently from the retaining of rare alleles (KANG 2001).

From the present study, some conclusions can be drawn that controlling the maternal fertility can increase effective number, and the final mix of nut will be a tradeoff between equalizing maternal contribution and obtaining an acceptable amount of seed. However, the increase of effective number was not remarkable by controlling maternal contribution for a clonal seed orchard of *P. koraiensis* (Table 2).

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